Trace Gases and Their Effects

An Interactive Qualifying Project Report

submitted to

WORCESTER POLYTECHNIC INSTITUTE

In partial fulfillment of the requirements for the

Degree of Bachelor of Science

by

Thomas Blaisdell

Joseph Leverone

Abigail Piva

Yuk-Kwan Yuen

Date: February 13, 2009

Professor Mayer Humi, Mathematical Sciences

Abstract

This project examined greenhouse gas emissions and their effect on the overall global temperature. A climate model was developed to simulate temperature rise as a function of emission levels. Using the model, various carbon emission policies were simulated to estimate the temperature increase in 2100. New technologies are expected to mitigate the impact of emission levels. Possible innovative strategies were researched, including clean coal technology, genetically modified crops, and biofuels. The strategies were analyzed based on feasibility and economic efficiency.

Table of Contents

Executive Summary

Climate change has become a severe problem that the entire globe is going to have to deal with through new technology and better planning for the future. The solution to this problem will come from research and new developments in efficient ways to produce clean energy. Although there are parts of the scientific community that underestimate the factor of human-caused climate change, we believe it is making a severe impact on the earth. The human race will have to adapt to mitigate this impact.

The main human sources contributing toward global warming are the burning of coal, vehicle emissions, deforestation, and general energy usage. Alternative energy sources and new technology combined with determined emission reductions are keys in reducing the human impact on global warming.

One of the most popular ways scientists and economic researchers plan for the climate change is through the analysis processes of computer models. In this project, a climate model was developed to predict the temperature rise caused by various greenhouse gas emission scenarios. These emission scenarios are a result of a changing input value for human effects towards global warming. The model was written using the computer program MATLAB. The outputs of this model predict the temperature changes that may occur. Based on the model results, the severity of human action can be judged. Using existing constants based on 2007 values, the climate model generated a predicted temperature rise of 1 degree Celsius by the year 2100.

After estimating the human damage to the planet, the most effective mitigation strategies were researched. We ran the model to find the most feasible amount of carbon dioxide emission reduction. Although the most drastic reduction would be the most beneficial, such a cutback would not be feasible due to cost and technology restrictions. Instead, we combined several plausible mitigation strategies. These approaches can be implemented all over the globe and achieve an optimal decrease in greenhouse gas emissions.

Introduction

Climate change is negatively affecting the earth's climate and will continue to for centuries to come. In order to grasp the severity of the problem, one must first understand its causes and consequences. This Interactive Qualifying Project (IQP) will provide valuable research and possible solutions toward controlling emissions. Working on an IQP focused on climate change will increase both understanding and interest in one of the greatest problems that our earth has ever faced. Responsible members of society need to comprehend this issue in order to vote responsibly in environmental and energy issues.

The relation between this project and the course of study as well as career goals are specific to each group member and are detailed below in the following paragraphs.

Thomas Blaisdell:

There are many purposed solutions for climate change that revolve around theories in chemistry. As a chemist, I feel that I bring knowledge of such theories to the group. With a chemistry position in an industry setting, I will be expected to use methods and purpose products that limit, and possibly reverse, the effects of climate change. This project will provide me with a good idea of the scientific hurdles that must be overcome if substantial advancements are to be made.

Yuk-Kwan Yuen:

The issue of greenhouse gases is attributed largely to the industrial revolution, where large numbers of machines were produced with little regards to the environment. Engineers should attain this environmental responsibility and produce machines that reduce greenhouse gas production. By applying new technologies and techniques, machines and factories can become environmentally friendly.

Abigail Piva:

Besides being a stimulating project, this IQP will also be helpful to my studies, in particular to my Environmental Sciences Minor. This IQP will give me the opportunity to utilize past education as well as learn new information that will be useful in pursuing my degree. Being conscientious of the environment and the cause and effect of human activity on it is both a personal and professional goal of mine. In the career I will have, I would combine the affect human production has on the environment into the engineering projects I will work on. When technology is able to work with the environment, rather than against it, is when the most beneficial projects are created. This project will give me experience on how to use technology to benefit the environment and experience on how to go about assembling a professional project.

Joseph Leverone:

There are many contributors to the release of GHG in the world, one of the biggest being transportation. My future plans are based around the automotive industry. The need for transportation in our society is not going to diminish; the change that must be made is in the way we move around. A more environmentally friendly form of mobility needs to be created. This cannot happen, however; until there is a better understanding of what quantity of GHG our environment can handle and how to properly regulate it.

An IQP provides students with a problem that is affecting society and can be solved using scientific methods. This specific project brings four different majors together to work toward providing the global community with new findings on the way greenhouse gases affect the earth. This project qualifies as an IQP because human caused climate change is probably the biggest, and most significant, problem facing the world at this moment. It has social, technical and ethical implications.

The accomplishments that will be achieved in this project combine research, understanding, and increasing mankind's knowledge of the surrounding environment. The research and resources that are used in this project will be from professional sources, scientists and engineers that have worked towards solving this great issue. This project serves to give a deeper insight into the global warming issue, and suggested policies that could reduce the carbon footprint of mankind. A closer look at global warming could uncover detrimental human behaviors contributing to the issue. By limiting destructive human behaviors, the future generations can continue to prosper. By implementing changes, one can take pride in the preservation of the world.

We sincerely hope the project can be viewed as a serious look into the damaged environment and possible remedies. Environmental agencies can benefit from our research in making further suggestions in policy change. The report can also be used to educate youths who are unaware of the issue that mankind is faced with. The combination of the two can bring fourth changes in the present and induce environmental responsibilities in future generations. In this sense, we would like this project to be available to anyone who would like to utilize it for either professional or personal benefit.

Background

Introduction

Science has made it clear that climate change has become a significant problem facing the earth and its inhabitants. An approach to resolving this problem will require economic development and research. The first piece of the challenge was to convince humans that climate change is taking place as a result of global warming and that the extent of it is severe. Over the past fifty years, there has been much debate over whether or not human activities have contributed to global warming. The IPCC (Intergovernmental Panel on Climate Change) concluded that there is strong evidence proving that a significant proportion of warming in the past one hundred years can be attributed to human activities. Some scientists expect the earth's temperature to rise by 5 degrees as early as 2030. The carbon dioxide levels in the atmosphere have been steadily increasing throughout human history, and are higher today than they have been in the past 650,000 years [67].

It is important to understand that some of the carbon dioxide in the earth's atmosphere is due to natural processes. Such natural processes included fires, variations in rainfall and volcanic eruptions. On average, the earth's oceans, trees and soils absorb about one-half of this naturally emitted carbon. The balance remains in the air and is responsible for the annual increase in temperature.

However, if emission levels continue to increase at the present rate, the rise in greenhouse gases would cause temperature to reach even higher levels. Carbon dioxide levels could rise from 550 ppm to 700 ppm by 2050 and 50 ppm to 1200 ppm by 2100 [67]. Evidence suggests that without any reduction, greenhouse gases are likely to reach the upper ranges of these predictions. These ranges are discounting the aggregate effects of positive feedback.

The profound impact of global warming will most likely be felt through changes in regional weather patterns. Continental regions and places at higher latitudes are predicted to experience temperature changes greater than the global average. On the other hand, tropical regions and coastal areas are likely to have less of a temperature increase.

The frequencies of heat waves are expected to increase as a result. In 2003, Europe experienced its hottest summer in 500 years [66]. The Hadley Center suggests that the summer temperatures that Europe had experienced in 2003 are twice as likely to occur in future summers. The research further suggests that the heat wave could become the norm with continuing high emission rates. European cities are expected to see a greater increase because of the heat island effect. This effect states that urban areas tend to have high temperatures mainly due to the reflective nature of urban development.

Because warmer air holds more moisture, rainfall will increase. This increase will be expected at higher latitudes, while, at the same time, drying will be more prevalent in the subtropics. Greater evaporation and increased rainfall will increase the danger of drought and flooding. Varying warming patterns around the earth will shift large-scale weather regimes. Weather regimes such as the El Nino may be adversely affected by the warming, causing large scale changes in the tropics.

Hurricanes and storm patterns are expected to shift across the globe. Recent evidence suggests that severe storms have become more recent. Research models show a shift of winter storms towards the poles. This could cause water scarcity in areas which depend on melted snow as a water supply.

Global warming is expected to trigger large-scale irreversible changes in the climate system. For example, the North Atlantic Thermohaline Circulation (THC) in the North Atlantic Ocean currently helps warm much of Europe and North America. As suggested above, the warming of the higher latitudes will weaken this weather pattern. The weakening is expected to lead to widespread cooling in Europe and North America. Recent ocean measurement shows evidence that the THC has already weakened by 30% in the last decade, but its significance is yet to be known [28].

Rising sea levels are another expected result of global warming. Sea levels respond slowly to the emission of greenhouse gases. The sea level rises as a result of expanding sea water and melting land glaciers. Warm air penetrates the water very slowly, meaning that the melting of the ice caps or glaciers are expected to occur over several centuries. As global temperatures continue to rise, sea levels could rise as ice sheets break off as well as melt on a large scale.

Some research suggests that the rising sea levels are mainly contributed to by water expansion and melting glaciers, discounting the effects of ice sheets. However, as global temperature increases, the possibility of the contributions of ice sheets increases as well. The scale and timing of the ice sheets becoming an effect are highly uncertain.

The Greenland Ice Sheet has shown accelerated movement towards the ocean as a result of global warming. Research suggests a temperature increase of 3° – 4.5°C could cause the ice sheet to melt irreversibility. The melting of the Greenland Ice Sheet could cause a several meter rise of sea level [25].

The overall recorded data shows a largely linear relationship between time and carbon dioxide concentration. The average annual increase is approximately 1.5ppm. However, there is little evidence to suggest an acceleration or deceleration of carbon dioxide concentration with this data.

The “Hockey Stick” debate has focused on whether or not the current rise in temperature is unprecedented or whether it is to be expected due to the natural variance of climate change. Although, there are large groups of people who still do not believe that human activity contributes to climate change, recent research from the Ad hoc detection agency came to the conclusion that while natural occurrences can explain some of the change in temperature, the only plausible reason for most of the change is human activity [66].

Today’s emitters of greenhouse gases (GHGs) will not have to face the consequences that their emissions will have upon the environment and the economy. For this reason, today’s society is struggling to gain an understanding of and deal with the hardships that future generations will most likely have to face. Understanding this, it is clear that human caused climate change is an externality. However, climate change is quite complex with respect to typical externalities. Firstly, due to the fact that GHGs diffuse throughout the atmosphere, climate change affects the entire world equally. In addition, unlike most externalities, climate change occurs at a very slow pace, which, in turn, slows the social reaction towards it. Also, given the huge number of causes and effects of climate change, there is a fair amount of uncertainty of what role climate change will play in the future. Furthermore, severe changes are in order to combat the effects that climate change will have on all aspects of society.

Some scientists, such as Dr. Meinhausen, have plotted the temperature trends of the 20th century, to emphasize climate sensitivities. His graphs indicate a long tail leading up to high temperatures. This is primarily because of the uncertainty due to clouds; if the clouds are too low to the earth then there will be negative feedback (cooling), but if the clouds are high and not blocking out radiating sun rays then there will be positive feedback (warming).

Scientists are beginning to realize that soon climate change itself will start to affect warming by reducing the natural absorption and releasing stores of carbon dioxide and methane. Rising temperatures combined with changes in rainfall patterns are affecting the earth's ability to absorb radiation. This, coupled with widespread thawing of permafrost regions, is going to add to extra warming. There are still many questions as to what the effects on warming due to climate changes will be. However, some scientists estimate that by 2100, the climate changes will have prompted the earth's temperature to be about 3-10 degrees Celsius higher. This could be disastrous because such warming would be much greater than anticipated [61].

Even if greenhouse gas emissions are dramatically reduced, the earth will continue to warm due to the effects of past emissions. Many past emissions have been absorbed by the ocean, and within the next few decades could reenter the atmosphere causing an additional 0.5° to 1°C.

If annual emission levels are sustained, the greenhouse gas levels at 2050 could double that of what they were at the pre-industrial period. The current concentration of 430 ppm of CO2 could reach a projected 550 ppm by the year 2050. According to the Hadley Centre, such an increase could mean a 2° to 5°C increase in mean global temperature ,beyond anything that human civilization has witnessed. [66]

After proving that human activity is the cause of high global temperatures, we must next establish the link between greenhouse gas concentrations and these high temperatures. In the 1820's scientists realized that the atmosphere lets more solar radiation in and less solar radiation out. Without this ability, the earth would be too cold to sustain human life. The chief gases that are responsible for trapping heat in the atmosphere are carbon dioxide, water vapor and methane. Water vapor is a very powerful greenhouse gas because warmer atmospheres trap more water vapor. Scientists have developed complex climate models that follow the earth's physical properties and give us a better idea of warming based on greenhouse gases present in the atmosphere. Climate models use data based on the laws of nature to simulate radiative balances and flows of energy. They encompass many different conditions like snow cover and wind speeds. These models tell us that even if greenhouse gases could stay at the levels they are at now, 430 ppm of carbon dioxide, the global temperatures would still rise by 1-3 degrees above what it is. This information tells us that the climate as a whole is more sensitive then scientists had originally expected.

The impending climate change will also require policy changes to reduce carbon dioxide and other greenhouse gas emissions. A popular way to present climate change policy is in terms of the social cost of carbon (SCC) and the marginal abatement cost (MAC). Ideally, it is assumed that as the cost of abatement increases, the SCC will slowly decrease. However, due to emissions of GHGs that already have and will have taken place, the SCC will most certainly rise as the MAC rises. This pattern will continue until carbon emissions are controlled [67].

Even though GHG emissions will affect all parts of the world equally, poor countries will be hit hardest by climate change. A lot of these poorer country's economies rely greatly on agriculture as a main resource. Unlike the rich countries, which are responsible for most emissions, these poor countries will fall victim to a deteriorating environment. With a need to form policy now, differences between the living standards of rich and poor countries will create diverging proposals to combat the effects of climate change. A method to advert these disagreements would be to forecast the impacts that climate change would have on individuals of different economical standpoints. Aggregating social utility would involve looking at how the loss of consumption opportunities would affect different individuals with varying standards of living. However, this system of aggregation would contain substantial problems. Certain rights and ethics may be overlooked when coming to a compromise. Because income is the most common aggregation factor, health and environmental quality can be disregarded. A truly fair approach to measuring social welfare would be to cover all measures of wellbeing including education, income, health, and environmental quality. However, comprising all these different factors will be no easy task.

The effects of GHG emitted into the atmosphere today will have a dramatic effect on us for a long time to come. One major problem in the fact that the mistakes made today will affect the future is that future generations have no way to be represented in current decisions. Because of this, the welfare of future generations has to be treated as equally important to the current. Our future generations being richer or poorer than the current will affect the climate change.

There are many risks and uncertainties about GHG, ranging everywhere from emissions to their impact. Future rates of economic growth and its impact on the volume of GHG emitted and the resulting temperature fluctuations are all uncertain. Our economic responses and policies regarding GHG are also uncertain due to the fact that the cost of reducing these emissions is unknown. The current policies try to judge and add utilities over other areas of the world that might be affected by climate change.

Climate Model Background

Climate models are simulations of the atmosphere, oceans, land surface and ice. These simulations provide quantitative data that can be used to study the dynamics of weather and to project the climate in the generations to come. Climate models are based on established physical principles and in the past have shown that they are able to reproduce observed features of the climate and reproduce past climate changes. Lately, they have been a vital tool in developing strategies to combat global warming. Climate models generally take account of incoming energy (radiation from the sun) and outgoing energy (the earth's reflection of the sun); any imbalance in the energies reflects the rise or fall in the temperature of the earth. Recently, models have been focusing on relating temperatures to emissions of greenhouse gases.

Some climate models focus on one specific aspect such as the oceans while others take into account factors such as the atmosphere, biosphere, geosphere, hydrosphere, and cyrosphere to model the entire Earth's system. The simpler models have mathematical equations that can be run on personal computers, whereas the complex models require supercomputers to perform the many calculations. All models must make assumptions about the components of the climate; many aspects of the climate do not have datasets and cannot be measured.

Climate Models/ Climate Model Uncertainty

Although climate models play a large role in this project, all climate models have a factor of uncertainty. They consist of numerically solved equations. Some equations can be derived from first principles, but many others have to be described in a simplified form. For example, there is no known equation to describe the effect of a growing tree on the climate, yet trees clearly modify the local climate and water cycle. Therefore the impacts of trees on climates have to be described using projected estimations, which limit the model because there is the factor of educated estimation instead of actual quantitative numbers. Another major component of the uncertainty is the chaotic nature of volcanoes. Their eruptions are difficult to predict and outcomes almost impossible to model [39].

A climate model has many uncertain parameters. One of the most important steps in developing climate models is to decide if the model itself is actually consistent with observations. Statisticians are able to rate the different climate models based on the climate models' predictions and the actual observations. Another glitch in the science of building climate models is the life cycle. Most models only last a few years, but the real need for climate models is for them to be able to make predictions for the future decades and even centuries.

Even with the margin of uncertainty that lies within climate models, they are not deemed useless by the scientific community. Models are able to reproduce observed global trends and they are tested on past climate data. Many of these models agree with observations on large scales which gives them credibility. Another credible factor of climate models is that they work based off of the earth's processes. This allows the models that use simple frameworks to make it easy for the user to both conceptually and theoretically understand the inputs and outputs [39].

Lastly, it is significant to look at the actual steps that are being done as a result of these climate models. The models are necessary for fighting the climate change problem. Even without perfectly accurate data, it is possible to gain insight and information from these models that can influence the decisions of global leaders now and in future generations on solving climate change.

The next sections of the background are provided to give in depth information on components of the climate. The research done on these several components was necessary for deducing their impact on the climate and specific to this project: the climate model we are creating. We came to the conclusion that due to the uncertainty and small margin of affect on the overall global temperature, some of these components shall not be included in our climate model. Please note that the next sections provide only the background information on each component as well as our reasoning for why we included or didn't include them into our model.

Volcanoes

Climate models take into account various conditions. One of these conditions is volcanic activity. Although not all climate models take this phenomenon into consideration, it does play a role in climate change. The actual climate forcing term is determined by several factors including net irradiance, mean temperature of the Earth, and a climate sensitivity parameter. When there are no volcanic eruptions, the equation is in "steady state." However, when there are eruptions the equation is not in steady state and depends on a response time. Response times can be anytime from 6 months to a year [43]. During this response time, ash and dust, which were emitted during the eruption, disperse into the atmosphere. While volcanoes are responsible for emissions, usually it is their ash that contains carbon dioxide and sulfur oxide. Scientists argue that volcanoes may actually cover up global warming because they cool the lower troposphere. Scientists thought that this dust emitted into the atmosphere from large volcanic eruptions was responsible for global temperature cooling. This would be due to the transmission of solar radiation to the Earth's surface. Yet, most scientists came to the conclusion that this affect is only temporary and lasts only as long as the response time of the volcano [44].

Graphs simulated by the International Panel on Climate Change depict that the increases in temperatures between 1950 and 2000 cannot be explained by natural causes alone and especially not by volcanoes seeing as volcanoes would depict a slight cooling in the climate graphs [55].

Cosmic Radiation

Cosmic radiation is mostly made up of photons, which originates from space. Other than photons, which make up 90% of the radiation, cosmic rays are made up of 9% alpha particles and 1% electrons. There are three general types of cosmic rays: galactic rays, anomalous rays and solar energetic particles. Galactic rays are the particles that come from outside our solar system. Most, however, come from within the Milky Way galaxy. More specifically, anomalous cosmic rays come from the interstellar medium, which can be found at the edge of the heliopause. The third type of cosmic radiation, solar energetic particles, is the atoms that originate from solar activity. Such activity includes solar flares and other solar events [5]

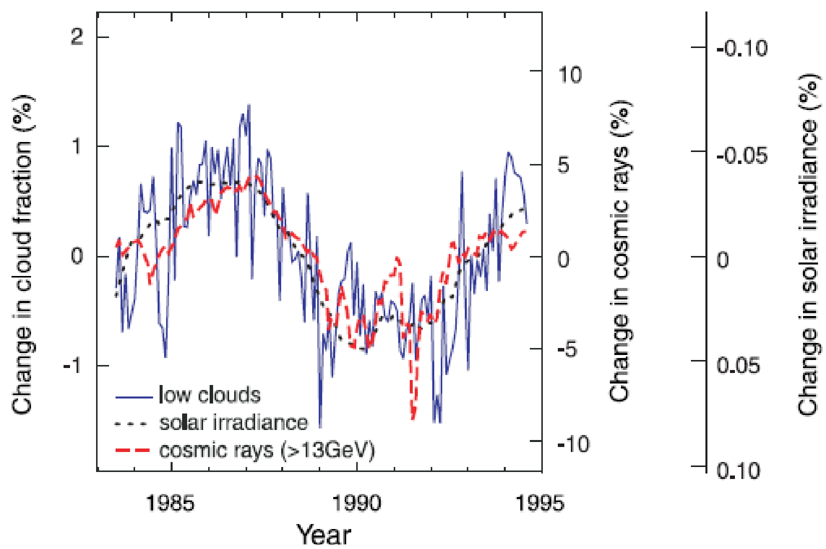


Figure 1: A plot of the variations in the levels of low clouds, solar irradiance and cosmic rays.

Many scientists believe that when cosmic rays contact the atmosphere, ions are created. Preexisting water vapor in the atmosphere is attracted to these ions. Once enough water molecules have attached to the ion, a small water droplet is formed. Clouds are made up of large amounts of these tiny droplets. Some scientists have speculated that the main contributor towards climate change is the variations in the amount of cosmic radiation that is hitting the earth. With smaller numbers of cosmic rays, fewer clouds would form, meaning more radiation would be absorbed by greenhouse gases [12].

However, not all scientists believe this theory. There are some who believe that there is very little evidence to support such a cause of climate change. Most studies have shown no decrease in cosmic rays in the past couple of decades. Scientists arrived at this conclusion after examining the Forbush events. These events are instances where there is an immediate increase in solar irradiance and a consequent decrease in cosmic rays. From 2000 to 2005, there have been 22 of these instances. When attempting to link these events to a reduction in cloud cover, scientists saw no connection. Sometimes cloud cover would grow while other times there would be a sharp decrease in cover. As more and more data is collected, the cosmic radiation theory has begun to show many noteworthy inconsistencies [13].

Solar Irradiance

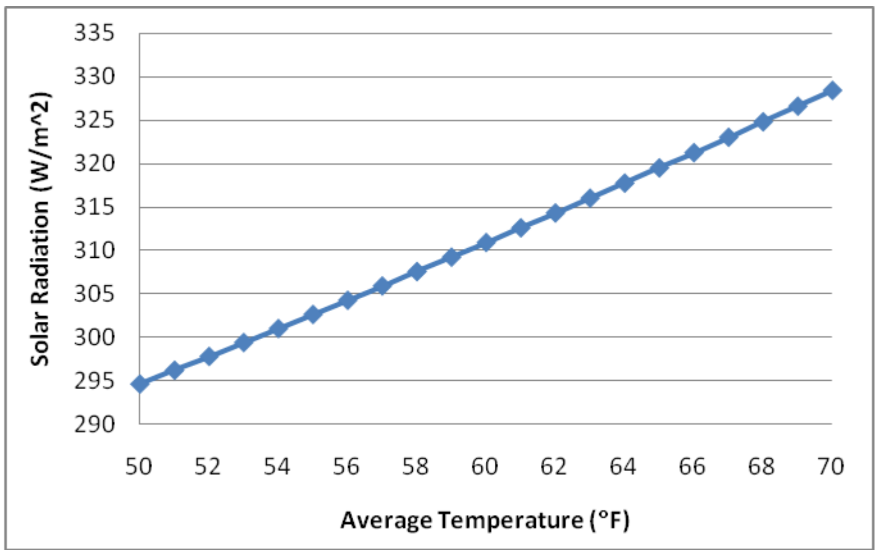


Figure 2: A plot of the global mean temperature (x-axis) and the solar radiation input (y-axis).

Another component of climate models is the net solar irradiance factor. Research has discovered that the average sun's irradiance has increased over the past couple of decades. However, this increase has a relatively small impact when compared to the effects that greenhouse gases have and will have on the earth and its environment. Measuring total solar irradiance is difficult for many reasons. Firstly, the sun has an eleven year cycle known as the Schwabe Cycle, and at different times the irradiance level is different. The most useful method for predicting climate change is counting sunspot numbers, these records date back to the 1600s. Using data collected from different sources, scientists have concluded that there has been a .05 percent increase since 1980s. This is a relatively small number compared to all the other components of climate change. [77]

There are mathematical equations that can model the global temperature and the global solar radiation. One of these equations is shown in the equations section of this paper. Using constants to solve this equation, one can observe the increase in solar radiation as the global temperature rises. At 57 °F, the estimated global temperature today, the sun is producing 305.9 W/m^2. If this average temperature was to be raised one degree to 58 °F, the solar radiation must be 307.6 W/m^2. This is a 0.54% total increase in solar output. That being said, if the solar radiation output were to increase by 1%, the temperature would rise by 2 degrees Fahrenheit. However, though this impact seems large, seeing that the increase in over twenty years is only .05 percent, it can be concluded that solar irradiance gives a relatively small impact to global warming.

Trees

Trees serve as an effective carbon sink for carbon dioxide in the atmosphere. Scientists estimate that forests and terrestrial components absorb about one-third to two-thirds of a billion tons of carbon each year. These trees are believed to then convert the carbon dioxide into biomass, storing the carbon within the tree trunks [52]. Although some scientists object to tree growth after exposure to the higher carbon dioxide concentrations, many have accepted that forests can act as a carbon sink.

Plant life and various forms of vegetations are shown to decrease the concentration of carbon dioxide in the atmosphere. An experiment was conducted from 2000 to 2005 to measure the average tree growth against carbon dioxide concentration. The experiment cannot confirm the direct connection between tree growth and CO_2 concentration, but noted that the carbon dioxide did not remain within the forest area. Instead, the report proposed that the gas was cycled through the trees and released into the soil through tree roots [58].

The heat island effect is a phenomena connected with large cities that experience greater temperature rise due to the close packed buildings. Trees planted in these heat islands serve as a means to reduce temperature and absorb pollution in these cities.

Also, trees can significantly reduce the amount of energy needed to power air conditioning appliances by reducing the overall temperature. Shades created by the canopy can redirect sunlight from the buildings, leading to lower building temperatures. Lower building temperatures also mean that less heat is radiantly transferred between buildings.

Evapotranspiration, the trees ability to transport water from the roots to leaves for evaporation, helps reduce temperature by adding moisture to the surroundings. "A mature tree with a 30-foot crown transpires approximately 40 gallons of water per day. Evapotranspiration alone can result in peak summer temperature reductions of 2 to 9°F (1° to 5°C) [73]." Stuttgart, an industrial city in Germany, extended the plan further by creating wind paths in the city to allow pollutant to escape as well as cool the ambient air. No new buildings are allowed to build on the designated wind paths after the 2003 summer heat wave in Europe, when these paths served effective in cooling the city. A recent study found that a turf-covered surface is 20 degree Celsius cooler than a tile-covered surface [63].

Trace gases and aerosols

A major component of the climate model designed for this project was the gases in the atmosphere and their affect on climate change. Although many trace gases and aerosols exist, this model mainly focuses on carbon dioxide and methane, two of the top contributors to temperature rise.

Carbon dioxide

Atmospheric carbon concentration has increased from 280ppm during the industrial revolution to 380ppm in the present day. The main carbon reservoirs are: the atmosphere, ocean, and terrestrial biosphere. As recorded by high accuracy measurements in the last 50 years, approximately 57 percent of the carbon dioxide emitted remained in the atmosphere [60]. The reminder went into the ocean and land biosphere.

For convenience to the reader, the extensive data trend is graphically depicted below. These data sets go as far back as 1991, and demonstrate a steady increase of CO_2 concentration in the atmosphere for the last 18 years.

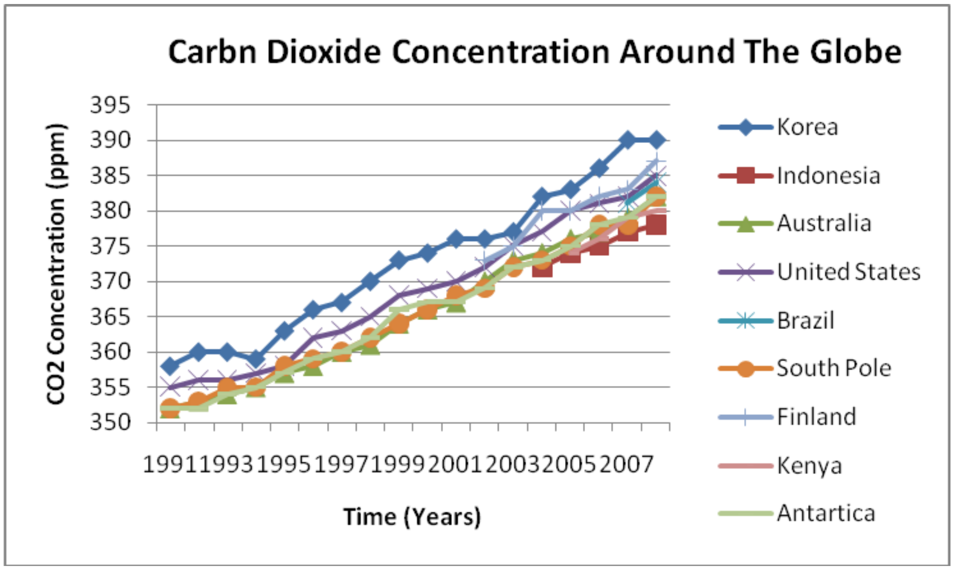


Figure 3: CO2 Concentration Data is taken from Earth System Research Laboratory. The data sets are concentrated on carbon dioxide alone, without consideration of methane, nitrous-oxide or any other trace gases. In order to fully understand the rise in carbon dioxide concentration, multiple data sets from different parts of the world was taken. These locations includes: Tae-ahn Penincula (Korea), Bukit Kototabang (Indonesia), Cape Grim (Australia), Niwot Ridge (CO. United States), Arembepe, Bahia (Brazil), South Pole (United States), Pallas-Sammaltunturia (Finland), Mt. Kenya (Kenya), Syown Statian, Antartica (Japan). All of the data sets are representative of the surface measurements [Error! Reference source not found.**]

More than 8Pg (Pg = 10^{15}g) of CO2 is released into the atmosphere by human sources. Approximately 1.7PG is absorbed by the ocean and 1.4Pg is absorbed by the biosphere annually. Every year, about 100Pg is transferred among the three reservoirs [60]. Global recordings found an increasing carbon concentration in the atmosphere. Since 1980, the global average of CO2 concentration has increased annually at 1.6ppm. But since the year 2000, the annual increase has been 1.9ppm [60]. These numbers suggests that the fraction of carbon dioxide that remains in the atmosphere may be increasing.

Methane

The total methane contribution to the radiative forcing is about 0.7Wm^{-2}, which is approximately half the effect of CO2 [22]. However, methane also has an effect of atmospheric chemistry by altering the concentration of OH and O_3 (a greenhouse gas) [22]. Methane emission since the industrial era is responsible for the half of the estimated O_3 increase in the atmosphere.

Nitrous oxide and sulfur hexafluoride

N_2O and SF_6 are much more efficient radiative forcing agents than carbon dioxide. N_2O is about 198 times and SF_6 is about 22,800 times more effective than carbon dioxide as a greenhouse gas. The global mean concentration of N_2O and SF_6 are 321.4ppb and 6.29ppb respectively, which is 1000 and 60 million times less than that of carbon dioxide [22]. Although their concentrations are relatively sparse, they are believed to cause a significant change in radiative forcing. N_2O added 0.16Wm^{-2} and SF_6 0.0029 Wm^{-2}, to the climate balance. N_2O is of special concern because it is a major source of ozone depletion, by reacting with O_3 to form NO. Both N_2O and SF_6 have experienced a steady gain of 0.778ppb yr^{-1} since 1977 [22].

Halocarbons

Long live halocarbons are effective greenhouses gases. Theses gases are effective in absorbing terrestrial radiation, and are responsible for the destruction of stratospheric ozone. The concerning ability of halocarbons to destroy the ozone is addressed in the 1987 Montreal Protocol. With the exception of H-1301, these gases have declined in concentration.

Some halogenated gases continue to increase in concentration. Most notably, HCFC and HFC, as these are the common replacement for CFCs, halons, and other ozone depleting gases. HCFC are less efficient at ozone depletion compare to CFCs, and HFCs has little relation to ozone depletion.

HFC concentration increase poses its own problems, since HFCs are efficient absorbers of infrared radiation. HFC-134a, the most abundant HFC is the atmosphere increased non-linearly in the 1990s. From 2004 to 2007, HFC-134a has increased steadily at 4.5ppt yr^{-1} [46].

The ozone layer can be gauged roughly from a sum of Cl and Br in long-lived halocarbons. The sum is expressed in a quantity referred to as EECI, an estimate of the ozone depleting power of trace gases in the near future. A second quantity known as ECI provides the same estimate in the Polar Regions.

Current observations show a decreasing tread of EECI and ECI from their 1994 peak values. Since 1994, the EECI and ECI decreased steadily at a rate of 25 to 28ppt yr^{-1} [46]. This analysis suggests that in 40 to 60 years, the EECI and ECI levels will return to their 1980 values. 1980 is when the ozone depletion was first observed, and a reduction to pre-1980 values could mean a full recovery of the ozone layer.

Cloud Cover/Water Vapor

Cloud cover is an important aspect when examining the earth's climate. In general, clouds tend to reflect the majority of the sun's shortwave radiation back into space. However, some shortwave radiation does make it through the clouds and is absorbed by the earth's surface. The earth also emits radiation, which is in the long wave form. Although some of this radiation escapes into space, most of it is reflected back to the earth. For this reason, clouds and water vapor can be considered the most prevalent greenhouse gas [17].

Not every cloud absorbs and reflects radiation in the same way. High clouds, also referred to as cirrus clouds, are usually found at altitudes above 8000 meters. Due to being so thin, cirrus clouds are transparent, meaning they have a small albedo and reflect the sun's shortwave radiation poorly. However, they do absorb the earth's long wave radiation well and, due to their height, reflect most of it back towards the earth rather than to space. Due to all these factors, cirrus clouds tend to increase global warming [18].

Stratocumulus clouds are very thick and are usually found below 2,400 meters. Because of their thickness, they have large albedos, meaning that they reflect shortwave radiation well. Due to the fact that stratocumulus clouds are very low to the earth's surface, the majority of the earth's long wave radiation is emitted into space rather than being reflected back towards the earth. Due to all these factors, stratocumulus clouds tend to cool the earth's surface [19].

One of the largest questions surrounding global warming is how rising surface temperature will affect the clouds. Rising temperatures would lead to an increase in the evaporation rate of the earth's oceans and lakes. This would eventually lead to more water vapor in the atmosphere. At this point, there is some uncertainty. Some believe that enough clouds would form from this additional water vapor that temperatures would decrease. Others think that the water vapor would stay mostly in vapor form and act only as a greenhouse gas. The presence and amount of cloud condensation nuclei will determine whether the water vapor will yield additional clouds. There is some uncertainty about how rising temperatures will affect the levels of these nuclei, also referred to as aerosols [69].

Mitigation for Global Warming

The world has seen an immediate need for mitigation strategies in global warming. In 1997, in Kyoto, Japan, the Kyoto Protocol was signed [40]. This set of regulations has been adapted by thirty seven industrialized countries to mitigate their emissions and lower them each year. The Kyoto protocol is a legally binding agreement in which the countries that have agreed to it will reduce their collective emissions by 5.2% compared to their emissions in the year 1990. This cut in emissions is expected to occur by 2012 [40]. It is a document that has been ratified by 182 countries in the hopes of reducing greenhouse gases. National targets range from 8% reductions for the European Union, 7% for the US, 6% for Japan and 0% for Russia. Certain countries were permitted increases such as Australia (8%) and Iceland (10%) [40]. (Note, the United States is the only industrial country who has not agreed to ratify the protocol.) The next section is dedicated to researching the most effective strategies countries could adapt in order to lower their total emissions.

Alternative Fuel

Scientists believe that replacing carbon rich combustion materials with biofuels could cause an 18% to 28% decrease in carbon emission [34]. Biodiesel or Ethanol has the potential to replace gasoline with new breakthroughs which will allow continuous production without destroying the planet. Ethanol has been proven as an alternative fuel in various vehicles, but its production process requires a large amount of corn. The direct competition with food suppliers is encouraging the plowing of grass lands, which increase the effects of global warming by reducing the amount of plants there are to sequester carbon. Algenol, a Maryland based company, has made strides by producing ethanol with algae. Instead of harvesting the plant itself, scientists are using an enzyme to enhance the process of converting sugar into ethanol. In essence, algae use sunlight, carbon dioxide, and seawater to produce ethanol, oxygen, freshwater and fertilizer. The process converts 1.5 million tons of CO_2 per 100 million gallons of ethanol produced [**Error! Reference source not found.**].

The plant is grown in large glass columns filled with seawater that are exposed to sunlight. Ethanol is then captured as a gas and condensed to a liquid. Algenol CEO Paul Woods says such techniques would help slash production cost in half compared to corn based ethanol. The company is expected to generate 20 billion gallons of ethanol by the year 2020 [21].

Clean Coal Technologies

The total world energy consumption is predicted to increase by 50% by the year 2020. Most of this consumption increase is due to developing countries that in future years will have a higher need for electricity than before. Today coal production is responsible for 80% of the global energy produced, being a recoverable, relatively inexpensive fossil fuel [27]. Many scientists have deemed that solar power is too expensive and nuclear power is too risky. Therefore, much of the energy producing weight has been placed on coal.

Coal production, however, produces several environmental concerns. Emissions such as SO_2, NO, NO_2, and Hg are a few of the harmful compounds released when coal is processed for making energy. Emission regulations are expected to get more stringent in the years to come and research is already underway for next generation power plants.

So far, research in controlling coal power plant emissions has proved that SO_2 emission control can be achieved with the use of precombustion technologies, such as fuel switching and limespray drawing. Another technique in controlling chemical emissions is FSI or Sorbent Utilization Enhancement. This consists of a highly reactive sorbent that undergoes nearly 100% utilization. FSI will be improved once researchers are able to develop cost-effective, largely available reactive sorbents [27].

More and more techniques are being employed to lower NO_x emissions. Such systems include lowering the combustion temperature by implementing staged combustion, lowering air preheating, and using low NO_x burners. These techniques succeed in reducing NO_x emissions by 35-45%. This percentage can be raised with the use of post combustion techniques such as selective noncatalytic reduction (SNCR) and selective catalytic reduction (SCR). Though both succeed in drastically reducing NO_x emissions, SCR is the more favorable system due to the fact that its operating temperature is between 280- 450 °C. This is compared to the operating temperature of SNCR, which exists between 850 and 1000 °C. SCR proves to reduce NO_x emissions by over 90% [27].

Carbon-based technologies are also used to reduce NO_x emissions. A popular carbon-based technology is the CARBONOX process. The process revolves around the reacting of NO_x-laden flue gas with activated carbonaceous materials. It converts NO to CO_2 and N_2. The benefits of the CARBONOX process are a theoretical reduction rate of 100% and the use of carbonaceous sorbents, which are well known in the coal industry. The OSCAR process is another popular process used to reduce emissions of harmful elements. Using a highly reactive CaCO3 sorbent, it is not only able to reduce NO_x emissions, but also able to capture trace elements such as Hg, As, and Se.

More and more steps are being taken to fight environmental pollution. The U.S. DOE's Vision 21 program is striving to eliminate all emissions. Coal-fired power plants would increase in efficiency from 33-35% to over 60% under the U.S. DOE's plan [27]. This increase could be achieved through advanced pulverized coal combustors, pressurized fluidized-bed combustors, and integrated gasification combined cycle. Because of this rise in efficiency, CO_2 emissions would be reduced by 40-50%. It is clear that with advancements in technology, there is more emphasis being put on the reducing of emissions. These technologies mentioned above are only some of processes that will have an effect on the world for years to come [27].

More Efficient Solar Power

Current solar cells only have an efficiency of about 15% to 20%, and a new technology known as quantum dots aims to increase this efficiency to above 30% [50]. Traditional solar cells are made from silicon wafers stacked together, whereas these quantum dots are made from bundled semi-conductors with a diameter of a few nanometers.

The reason that these quantum dots can have twice the efficiency of the silicon solar cells are based on the idea of "holes" in these semi-conductors. Silicon wafers will only allow one hole for an incident photon regardless of the energy level of the incident particle. On the other hand, quantum dots respond differently when excited by a photon with different energy level. This is made possible by the quantum effects based on the size of the quantum dots. Large dots would have a larger energy hole that would absorb a high frequency, and thus higher energy level photon. The non-uniform structure of quantum dots also allows one incident photon to produce multiple excitron if the incident energy is great enough.

The difference in absorption behaviors between silicon wafers and quantum dots translate to a border range of absorption and more efficient absorption for a given wavelength. By stacking quantum dots with different response wavelengths, the incident sun light can be used more efficiently by absorbing a greater range of frequencies. Such techniques are now being considered as "Rainbow Solar Cells" because of the cell's ability to absorb and use a broad band of colors to produce power. In a traditional silicon cell, the extra energy would just be wasted as heat. The multiple excitron production also translates to a greater energy production given a single photon. Higher energy incident rates will produce more energy in the cell instead of just creating unproductive heat. The quantum dots solve the inefficiencies related to traditional solar cells, with their ability to use the excess energy of an incident photon.

Cost-Effective Solar Power

The largest problem with current solar panels is the time required for manufacturing, and its subsequent cost. However, a company known as Nanosolar has invented a low-cost printing mechanism that has successfully reduced solar panel cost by $10.

Traditional solar panels are made with expensive silicon, which then have to be put on glass panels. Furthermore, silicon requires time to crystallize and settle. The process also proves to be wasteful as well; 70% of silicon is lost in the process [70].

Nanosolar uses the principles of printing in manufacturing solar panels to significantly reduce cost. The company has successfully printed semiconductors onto rolls of aluminum, which require no settling time. The printing process also means very little is wasted, as only the required amount of coating is printed onto the sheets themselves [71].

Besides the ease of production and low-cost process, the resulting solar sheets are flexible and lighter than existing solar panels. Glass casings in present solar panel require heavy mountings and costly installation fees. The sheets can be fixed onto various surfaces with ease while producing equivalent amounts of solar energy.

Coal Substitute

Coal burning remains the major fuel used in power generation. In the Unites States, coal is used to provide 51% of the energy needed, and contributes 80% of the carbon dioxide emissions of the nation [10]. Governmental regulations are expected; several states began implementing laws requiring a reduction in carbon emission. For example, Minnesota required all utilities companies to obtain 25% of their power from clean sources by 2025. Colorado Governor Bill Titter wants his state to decrease carbon emission by 20% before 2020 [21].

The direct relationship between global warming and carbon dioxide emission is causing energy companies to use alternative fuel. Since last year, the construction plans for over 70 coal burning plants have been cancelled across the nation. Wind and solar power generation have seen revived interest as positive substitutes to coal.

PSEG Global, a utility company, successfully combined the principles of wind energy and excess energy to lessen the power needed at peak hours. The plan is to use excess energy during off-peak hours to drive wind turbines and compress air into storage, in places such as underground caverns, or above ground tanks. The compressed air is then released onto generator turbines during peak hours to produce electricity. This new system is 25% cheaper than battery storage, a commonly used practice today [21]. Compared to traditional wind powered generation, this new system is expected to have one-fourth of the response time. Quicker response time ultimately leads to a more stable power grid with less intermittence [54].

Enertech has created a way to make coal substitute from human waste. The system not only produces alternative fuel, but also acts as a waste treatment plan. Wastes are first collected from the sewage system and are then mixed into homogenous slurry. Under pressure and heat, which prevents the slurry from evaporation, the slurry is then chemically broken down. After the carbon dioxide from the slurry is released, the solid that remains can be used as fuel [65]. The company promises zero-net carbon emission, since the carbon dioxide released in the process was coming from waste products.

E-Coal takes a similar approach to Enertech in drying bio mass and condensing the energy content of biomass. This utilizes the patented process known as ECO-Torrefaction. Biomass, such as wood, seaweed, algae, and agricultural waste are collected and put into a low oxygen content chamber. The chamber is then heated to 250°C. At this temperature, the organic pollutant and smoke forming volatiles are separated. The end result is a very condensed biomass that has the same energy density as coal [4]. The company claims that their products are carbon neutral, and that a 20% mix of coal and E-coal correspond to a direct and immediate 20% decrease in carbon dioxide emission.

Transportation

One of the greatest contributors to global warming is the growing numbers of personal and public vehicles. Several scientists from the Alamos National Laboratory is now conducting research to replace the common internal combustion engine. The researcher also came up with a temporary solution aimed to convert the emitted carbon dioxide into gasoline. The exhaust would be blown over a liquid solution of potassium carbonate, which would react with the carbon dioxide to create methanol, gasoline, or kerosene. This system would keep the carbon dioxide in a closed system, and would not contribute to the overall GHG emissions. Although the technology is readily available, the system is cost prohibitive to implement. In order to produce the fuel on a commercial level, considered at 750,000 gallons a day, there would be a need for the factory to have a dedicated power plant. Other sources of alternative fuel are more cost effective.

Liquefied Natural Gas (LNG) is currently being used as a replacement for petroleum based fuel. Cooling natural gas to -260 degrees Fahrenheit reduces volume of the gas, making the gas much more cost efficient to transport [**Error! Reference source not found.**]. LNG is transported in cryogenic tankers as opposed to a pipe line but still remain economically competitive against petroleum derived diesel. However, LNG is more expensive to produce and refine compared to common gasoline. To produce LNG, a production train is needed to liquidly the natural gas. The largest production train is located in Qatar with an annual capacity of 5.20

million metric tons [**Error! Reference source not found.**]. The difficulty in production limited LNG to become a widespread energy source.

Automotive application of LNG technology is limited in commercial trucks. In the United State, the Westport Company is collaborating with Kenworth to build 17,000 trucks to be used in California. The engines are CARB certified to 0.8g/bhp-hr NOx and 0.01 g/bhp-hr PM [38]. The engines only required a small amount of diesel to ignite the natural gas, and produce nearly identical performance as conventional engines. Besides LNG, other fuel replacements are being considered.

Hydrogen motors and hydrogen fuel cells are currently being researched and developed to replace conventional engine. The fuel stacks reacts hydrogen with oxygen in the air to produce electricity, while producing environmentally neutral water as a byproduct. The electricity generated will be used to drive an electric motor, which will achieve similar performance and costs compare to existing engines. For example, a 100kW fuel cell could be produced for about three thousand dollars [74]. However, Current technologies are insufficient to survive the abuse of day to day operations. The fuel cells are easily damages by the bumps and irregularities of today's roads, and the hydrogen fuel can also be easily contaminated. There are many ways that current automobiles can be improved before these technologies can be augmented.

Increasing the efficiency of automobiles' air conditioning units is a cost effective measure to reduce carbon emission. Research estimates that The United States consume about seven billion gallons of gasoline per year from air-conditioning use [75]. Another technology that can be implemented is a refrigerant leak detector. The refrigerant used in A/C system is a potent greenhouse gas, and is extremely damaging to the ozone layer as well.

Refrigerant recharging machines can significant reduce refrigerant (CFCs) from leaking into the atmosphere during service. Existing techniques allow a significant amount of refrigerant to leak out into the atmosphere before resealing the system. Newer machines can effectively eliminate this leakage [75]. The reduction in CFC released would be equivalent one million metric tons of carbon dioxide, or the emissions of over six hundred and fifty thousand cars [75]. The efficiency of current automobiles can be increased by reusing the energy in the exhausted gas.

Heat from car exhaust can be used to power onboard hybrid motors. A unit mounted on the engine containing water at a high pressure would be stored in a closed system with a gas turbine. The heat from the engine's exhaust would be used to super heat the water into steam, which would be forced into the turbine. A generator coupled to the turbine would assist the engine in recharging the electric batteries on the hybrid.

With the election of President Obama, there are now proposals for stricter EPA regulations. The current standards are 27.5 mpg for passenger cars and 22 mpg for light trucks [6]. The proposal currently on the block is to allow each state to set their own EPA standards; this would allow states such as California, who would like to increase the standards well over the current federal standards, to regulate themselves. California, under the Clean Air Act, is looking for a 30% reduction in green house gasses by 2016. This reduction would translate into an average of 35 mpg for automakers. By 2020, California is looking for automakers to average about 42.5 mpg [6]. The current CAFÉ plan calls for the fleet average by 2020 to be 35 mpg [82].

Along with the increase in standards, there is another difference between the California and CAFE Rules. The CAFÉ standards regulate the fuel economy of production vehicles, while the California rules look for reductions in GHG emissions.

Surface Albedo- Buildings

The earth's energy balance is dependent on the reflectivity the planet's surface. A more reflective earth surface would lead to a cooler environment by reflecting the incoming energy from the sun into space. Urban areas make up 2.4%1 of the world's total surface area. Paved roads and roofs comprise of only 35% and 25% respectively. Artificial surfaces, such as asphalt, building surfaces, and walkways have the potential to be modified most readily to reflect more sunlight. However, to whiten 100% of all of these surfaces would cost about 50 trillion dollars, and needs a new coat every decade. [2, 33]

Crop Growth

Researches published in "Current Biology" conclude that more reflective farm crops can significantly lower global temperature. British researchers believe that this strategy could cool much of Europe, North America and parts of Asia by one degree Celsius during summer months. A one degree difference in the mean temperature could be sufficient enough to prevent heat waves and droughts in these areas. If farmers adopted this strategy by the end of the decade, there would be a 20 percent reduction in the expected temperature rise in the next century [37]. Leader of the study, Dr. Andy Ridgwell, states that researches have shown that the reflectivity of wheat, maize, barley, and sorghum is related to the texture of the plant's surface. The strategy would be most effective in areas of the world where most of the croplands are located, such as Europe and North America. The agricultural cooling scheme would be ineffective in countries closer to the Equator, where the extra heat being reflected from the plants could shrink cloud cover and allow more sunlight to enter the atmosphere. To encourage the growth of high reflectivity plants, farmers would receive carbon credits or other monetary benefits as encouragements. Participating farmers are expected to earn in 23 Euros per hectare per year for the warming averted. Biofuels currently earn 45 Euros per hectare per year, but take up competes against food crops for agricultural land. Other researches focus on wild plants, which cover even greater parts of the earth's surface. [27]

A California research team attempts to manipulate the albedos of agricultural and forest areas to advert the effects of global warming. Plants differ in their albedo because of differences in the leaf's surface properties and the canopy morphology of the leaves. Plant breeders have created a plant known as Soya, which is identifiable by its extra-hairy texture. The plants have the ability to resist pests, and reflect an additional 5% more sunlight than normal. [27] Soya has been planted across 1 million square kilometers in Brazil, Argentina and the U.S. The immediate areas have already witnessed temperature reduction. The research team emphasized that this crop would not disrupt food production, unlike plants being used to refine biofuels. Over the next hundred years, high reflectivity plants could possibly reduce the carbon footprint by 195 billion tons of CO_2 in the atmosphere. This simple alternative could reduce the severity of heat waves at a low cost.

Genetically Modified Crops

Genetically modified foods, also known as GM foods, can prevent the expected famine bought on by droughts with increasing global temperatures. Many environmental organizations have been actively protesting these crops as they believe they will bring harm to nature. The term GM food is used to refer to crop plants that have been created for consumption using the latest molecular biology techniques. These plants have been modified to enhance traits like resistance to herbicides and droughts. Genetic engineering can create plants with the desired trait very quickly. For example, a scientist can splice gene responsible for drought tolerance into a different plants, creating new plant with the same property. Not only can genes be transferred from one plant to another but genes from non-plant organisms can also be used. The growing global population and the predicted drought would create many societal problems.

The current global population stands at 6 billion people, and is predicted to double over the next 50 years, a food supply that can match this population increase would require the growth of more tolerant food crops. GM food can be engineered to be pest resistant, and eliminate the application of chemical pesticides, reduce the cost of crops, and allow crops to be grown in more areas. The modified plants are also resistance to viruses, fungi and bacteria that cause plant diseases, and increase crop yields. The improved breed will also be tolerant to droughts, so that crops can still be grown in the drier weather resulting from global warming. Countries depended on the annual monsoon would be able to grow more crops over the year.

Besides drought, floods are estimate to destroy four million tons of rice every year, enough to feed 30 million people. [49] Temperature changes, rise in sea levels and worsening weather patterns are making flooding one of the major causes of rice crop loss. A new breed of flood tolerant rice has been discovered by Professor Pamela Ronald. Rice is a staple for about half of the world’s population, and a sustained supply of rice could potentially benefits millions of people. [49] Despite their advantages, the mutated crops have their own problems.

Many professional organizations have criticized both agricultural businesses and the government for not researching potential human health hazards, environmental hazards, and economic concerns related to the modified crops. Although the risks of these mutated pants are unknown, they serve as a promising solution to the pending food shortages.

Plankton

The plankton in the world's oceans is absorbing and sequestering a large proportion of the carbon dioxide that exists in the ocean. When the plankton dies, some of the CO2 that it had absorbed is trapped and is sequestered within the sediment on the ocean floor. Rising ocean temperatures is killing off a significant fraction of the plankton populations. This is due to the fact that important nutrients are becoming scarcer. Not only do shrinking plankton populations increase the amount of CO2 in the atmosphere, but also impacts the oceans food chain. Plankton occupies a large proportion of the base of the food chain in the oceans.

Most plankton spores from natural occurring iron, which comes from volcanic rock. Some scientists believe that by introducing iron into the oceans, plankton populations would increase immediately. However, there is still a large amount of uncertainty of the effects that this iron would have on the oceanic environment. [47]

Biofuels

The use of biofuels is another promising strategy in reducing greenhouse gas emissions. The use of specific types of algae has been the center of much research. These algae absorb carbon dioxide and nitrous oxide emissions that have been dispersed into the atmosphere. There are many different types of algae, some of which sequester larger amount of gases then others. These algae form oils that can be used as a petroleum alternative.

Scientists believe that the best location to grow algae would be in arid deserts due to the fact that there is a lot of sun exposure and little to no human activity. It is predicted that it would cost 46.2 billion dollars for algae farms to fulfill the power expectations of the United States for one year. This is relatively inexpensive when compared to the $100 million dollars spent annually by the U.S. to purchase foreign crude oil. [20]

Wind Power

The use of wind power could potentially reduce emissions drastically. Scientists in the United States believe that by 2030, 20% of the nation's electricity could be produced by wind power. A significant increase in the numbers of wind turbine and a more efficient power grid would be needed in order for this to succeed. However, the most important step is for electric generation industry to view wind power as a viable option. If these steps were accomplished, the effects of wind power would be enormous. Electric utility natural gas consumption would be reduced by 50%, while electric utility coal consumption would see an 18% decrease. By 2030, CO2 would be reduced by 825 million tons every year. In addition, 17% of the water consumed by the electric sector would be saved. Such a plan would be inexpensive as well, as each household is expected to contribute only $0.50 a month to create this infrastructure. In additiona, an estimated 500,000 jobs will be created directly, and an additional 150,000 indirect jobs. Needless to say, harnessing the natural power of wind could prove to be a viable option in facing the impending climate change. [**Error! Reference source not found.**]

Kite Power

A group of scientists claim that a kite-powered generator could produce energy equivalent to that of a nuclear power plant. When wind hits the Kite Wind Generator (KiteGen) a kite is released from a series of arms extending out in a circle around the core generator, resembling a merry-go-round. There are a series of cables connected to each of the kites, so that an operator can control of the direction and pitch of each kite. The control system will adjust each kite for optimum efficiency depending on the changing weather patterns. KiteGen is also coupled to a radar system to move the kites if required. The kites will be made from a lightweight and tough material that would allow them to reach an altitude of up to 2,000 meters. The air stream would pull the kites and cause the core of the KiteGen to rotate, acting as a large alternator, and produce energy. Kite power is not a purely academic exercise, and is being considered for implementation in Italy.

Results at Sequoia Automation show the KiteGen could produce one giga-watt of power at a cost of 1.5 Euros per megawatt hour. This is a dramatic increase from the European average of 43 Euros per megawatt hour. Each of the generators would cost approximately 360,000 Euros and would span about 100 meters (320ft). Larger generators spanning 2,000 meters could generate up to five giga-watts are being built. The Italian government is considering kite power as a renewable energy source to replace energy generation by up to 22% to meet the EU Renewable Energy Directive [42].

Reduction from Combined Mitigation Strategies (Expected)

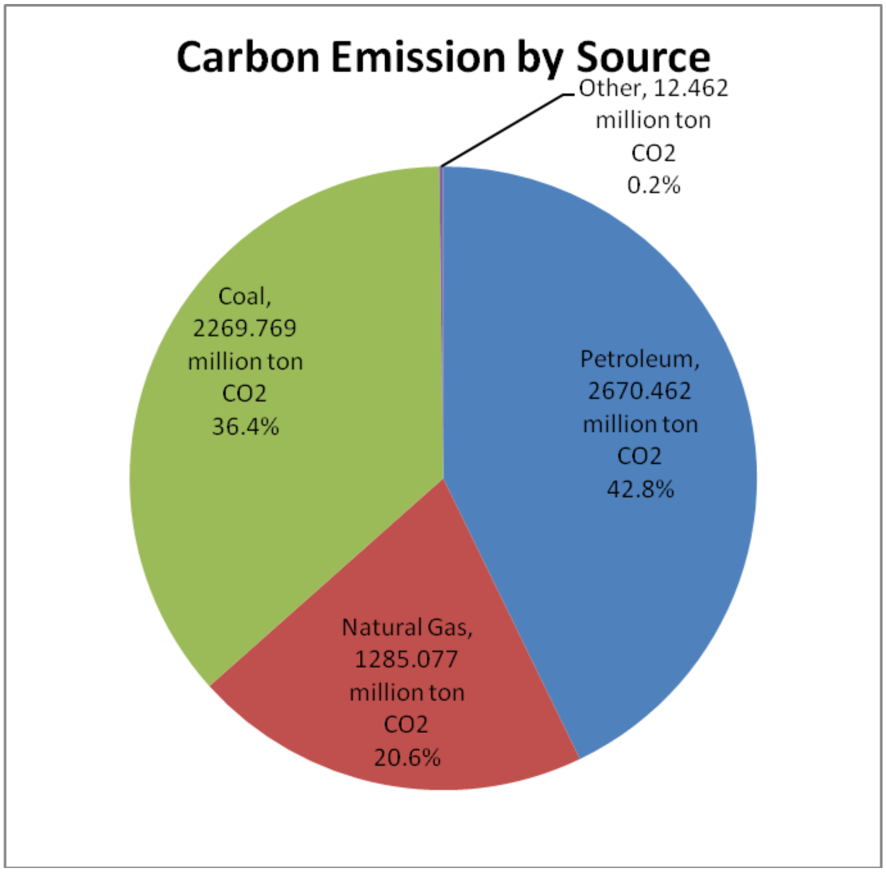


Figure 4: Carbon Emission by Source

Assuming that the mentioned strategies can be applied on a global scale through out the world, or at least the most polluting nations, an expected human pollution reduction can be approximated. To understand the impact that these mitigations strategies could have on the environment, an understanding of the current situation is required. From the Energy Information Administration, the break-down of energy is shown in Figure 4: Carbon Emission by Source.

A scenario can be constructed from assuming that only portion of these technologies are applicable to the existing climate, and that only a portion of their promised effectiveness is achieved.

Solar power may only be able to replace 5% of the total energy used and that wind power can only achieve half is effectiveness, and replace 25% of the power supply. Both of these technologies require large open areas for installation, and many residents may see installing solar panels and wind turbines as an ungainly sight, some may even consider wind turbines as a potential source of danger.

Biofuels could reduce 18% to 28% from the petroleum's polluting effect. Refining biofuel is still not widespread and the supply is limited, furthermore, conventional power plants and automobiles may not be able to accept biofuel as a substitute. In which case, only half of the 10% can be considered as effective. The automobile industry is expected to reduce emission by 40% in the coming years. This thought is calculated through the average of the company's range, meaning that companies can produce a heavy consumption vehicle and a light vehicle, as long as the average consumption hits the target. With that in mind, the less consuming vehicle may not necessary be produced in great numbers. Therefore, only half that effect, 20%, is assumed to have an effect.

Clean coal technologies promise a 40% to 50% decrease over conventional power plants. However, these conversions are sometimes cost prohibitive to adopt, and only 20% of the claim is considered. Coal substitution is a source of direct coal replacement, and promises a carbon neutral solution to power generation. The production of coal substitution is limited, and is expected to have a sustainable process to replace 15% to 20% of the world's supply of coal while maximizing the plant's production capabilities. Plant managers also have doubt about the performance of the coal substitute, so only 8% of the claimed reduction is accounted for.

Available Technologies	**Reduction**
Solar power	5%
Wind power	25%
Biofuel	10% x 42 % total
Automobile	20% x (50%) 42.8 % total
Clean Coal Technologies	20% x 36% total
Coal Substitution	8.0% x 36% total
TOTAL	**48.60%**

Figure 5: A table of mitigation strategies

The total reduction would achieve a 48.60% reduction overall, the simulation will model this reduction as an approximate value of 50%. A second more conservative model will also be modeled, with only a 30% reduction.

Technologies such as these needs to be implemented over a period of time so that supporting infrastructure can be built and that people's mind needs to be changed to accept these changes. Solar and wind power will require the construction of solar stations, wind turbines and connecting power lines. Green algae required for the refinement of biofuel is planted in a controlled environment in specific locations that can supply large amount of sunlight and fresh water. Accounting for all these changes, a time frame of 50 years was established. In which case, the 50% reduction is expected to occur over 50 years (2010 to 2050).

Procedure

A climate model is created to evaluate the different mitigation strategies introduced. The model is based on the energy flow of the earth's atmosphere. Every factor was considered, and with further research the model was simplified for ease of implementation. In the end, only crucial artificial components were considered. Appendix 1 shows the original flow chart, whereas appendix 2 shows the simplified model.

Original Model &Assumptions

The complexity of the original model contained too many variables, and became unfeasible to create given the scope of the project. Some parts of the model are now modeled with constants, and several positive feedback loops have been eliminated as well. The project is focused on greenhouse gases, and the direct temperature increase caused. Various researchers have indicated these to be the most significant factors in earth's energy balance.

The eliminated variables include: urban area albedo, aerosol effects, sun output, and the positive feedback link between ice melt and greenhouse gases, as well as its contribution to the cloud coverage.

Urban area modifications were deemed to be insignificant and too costly for implementation. Artificial surface only accounts for 2.4% of the total earth surface and has therefore been deemed insignificant. In order to modify all artificial surface albedo by one half, an estimated 500 billion dollar investment is needed. Also, these changes will need to be reapplied every ten years, so the cost investment required to sustain the albedo change could be better spent elsewhere. The urban areas surface albedo will be considered as a constant throughout the model.

The effects of direct aerosols are being neglected to simplify the model. The direct cooling effect of aerosols comes from its ability to reflect sunlight. More importantly, this pollutant in the atmosphere serves as nucleation sites for clouds. The small particles give rise to the formation of high-reflectivity clouds by creating smaller water droplets. This indirect effect would be demonstrated by cloud coverage. Scientists and researchers have not been able to gather enough information on cloud coverage to pinpoint quantitative data. This model makes an assumption based on the widely accepted hypothesis that at any given time 50% of the earth is covered in clouds. This is a hefty assumption because it does not take into account the type of clouds covering the earth.

The changes in sun's output show little variation over time and are therefore considered as a constant. This is due to the fact that there are many inconsistencies in the past solar cycles and the overall changes in sun output are small.

Cloud coverage plays a major role in the energy balance process because clouds are highly reflective entities. An estimated 63% of incoming sunlight is reflected by clouds, and is mostly caused clouds and aerosols in the upper atmosphere. Incoming sun rays are reflected by clouds in the upper atmosphere, and the incoming rays will never reach the surface. At the same time, the earth also emits radiation energy which is reflected back to earth by clouds. Planetary cloud coverage is the dependent on the water cycle.

Cloud coverage of the planet is linked to the water cycle on the surface. Temperature increase and permafrost melting provide possible changes in the system. A temperature increase in the ocean surface will allow the water to evaporate more readily and form clouds. The same temperature increase will cause permafrost to melt, introducing freshwater run-off in the ocean. Freshwater from melted ice has a lesser latent heat when compared to salt water, and could also affect the thermo-haline circulation in the ocean.

The complicated effects of the water cycle and cloud generation is convoluted and complex. Cloud generation is found to be outside of the scope of the project, and would not be considered in this model.

Actual Model

Energy Inputs/Outputs

This model attempts to simulate the total energy retained within the atmosphere. Energy retention is largely focused on the effects of the atmosphere and surface. Incoming energy is provided by the direct output of the sun.

Atmospheric energy retention is dictated by the greenhouse gas concentration. These gases include carbon dioxide, methane, carbon monoxide, and various halocarbons. These trace gases absorb the long wave radiation admitted by the earth's surface and release radiative energy. Some of the energy is radiated into space, while other energy is redirected onto the earth's surface. Simply speaking, the greenhouse gases form a blanket over the planet's surface insulating the lower atmosphere.

Greenhouse gases in the atmosphere are produced by several methods, such as human emissions, permafrost thawing, and natural phenomenon. Carbon dioxide is readily reused by plant life through photosynthesis, sequestering the carbon in soil and plants. On the other hand, methane is released into the atmosphere directly until it is chemically broken down. Other gases such as halocarbons and nitrous oxide add to the problem, but exist in lesser quantities.

Concentration of these gases can be modeled mathematically with differential equations based on their relative interactions on the planet. For example, carbon dioxide emissions are released into the lower atmosphere, and are then transported by air flow to plant lives and the ocean mixing layer. Eventually, plants will re-release the sequestered carbon into the atmosphere, and the ocean mixing layer of carbon will be transported into the deep layer of the ocean. Similarly, methane is released into the atmosphere by animal activities and permafrost melting. The methane will be transported to the upper atmosphere, while some is sequestered into the ocean.

Ice and permafrost plays an important role in the energy balance by releasing sequestered greenhouse gases. Large amounts of trace gases are sequestered in the ice and soil of these surfaces from the last ice age. As the surface features melt, greenhouse gases are released back into the atmosphere. Similar to clouds, ice also increases the albedo of the earth's surface, and the disappearance of the ice covered areas will have adverse effects on the earth's surface.

Methodology

Several assumptions need to be made in order to simplify the entire atmosphere into a zero-dimensional model. All spatial considerations are neglected, meaning the trace gases are perfectly mixed within the atmosphere, sun radiation rays are constant over the surface, and the exposed surface has a near constant composition.

Greenhouse gases will be modeled after the existing CO2 model provided, as the resulting data is shown to be accurate to an acceptable extent. The same mechanism transports these trace gases within the lower and upper atmosphere because they are all initially released into the lower atmosphere and diffused into the upper regions. The expected concentration of various gases is presented earlier in the report and will not be repeated here.

MATLAB Program

MATLAB is a programming language that is useful for quantitative computing. Cleve Moler, the chairman of the computer science department at the University of New Mexico, invented MATLAB in the 1970s to give students access to programs without them having to learn Fortran. In 2000, MATLAB was rewritten to use a newer set of libraries for matrices. The program allows easy plotting of functions and data, implementation of algorithms, and creation of easy user interfaces. A special added program adds graphical simulations and Model-Based design for dynamic systems.

Vital Equations

Green House Gas Concentrations

The differential equations used in this project are structured in a generics format. The idea was originally used in the *Introductory Carbon Dioxide Model*. These differential equations are based on the idea that different parts of the earth's atmosphere and surroundings can be divided into discrete parts known as reservoirs. These reservoirs are in turn interconnected to each other either directly or through the other reservoirs.

The diagram shown below is copied from the *Introductory Carbon Dioxide Model*, and describes the inter-connection between the seven reservoirs.

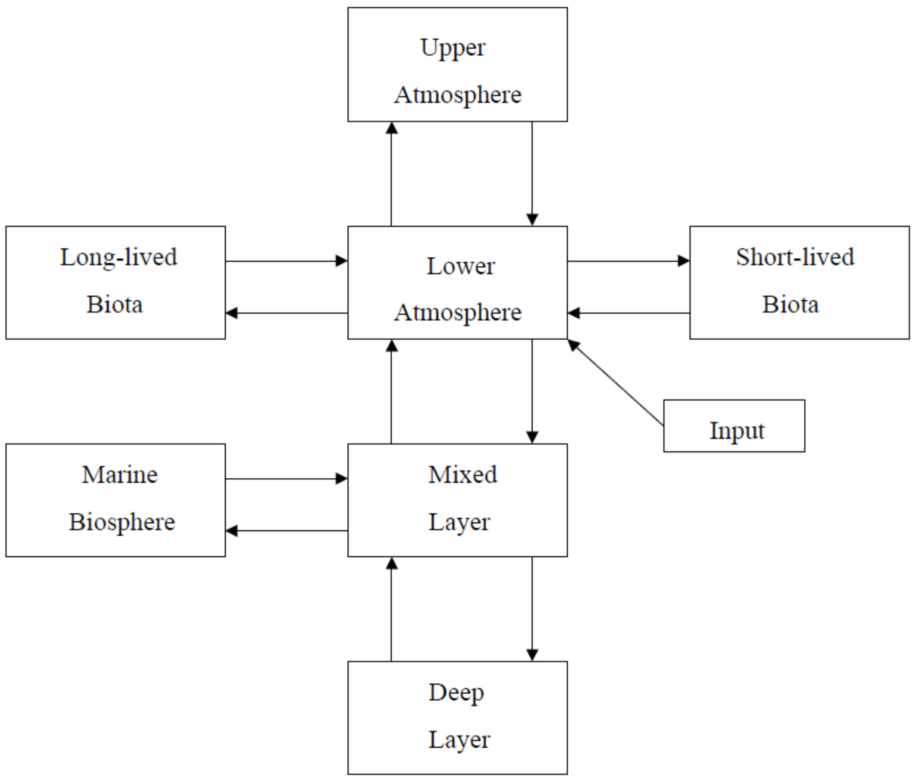


Figure 6: A diagram showing the inter-connection between the seven reservoirs.

Every set of arrow heads indicate a direct link between the two reservoirs' interconnection of carbon concentration. As shown in the diagram, for the carbon to travel from the long-lived biota to the deep ocean layer, it must first pass through the lower atmosphere and mixed layer before arriving in the deep ocean layer. While travelling through this path, some of the carbon will be scattered to the marine biosphere and the short lived biota, as well as the upper atmosphere.

The interconnection and diffusion of the carbon originated in each reservoir is encouraged by the difference of concentration between the reservoirs. So the equation can be written as (for the upper atmosphere):

$$d_{UA} = \frac{1}{K(C_{LA} - C_{UA})}$$

A constant K is introduced, and it is the residence time of the carbon dioxide. What the constant K translates to is that only a fraction of the difference can travel to the lower concentration atmosphere. Physical definition of this constant K is in the long-lived biota.

Given that trees and other annual plate lived can live for up to and over one century before they are harvested or naturally decompose in the forest. In that case the residence time of the carbon sequestered in the tree will have a value of 100, or a number of that magnitude. So for the lower atmosphere and the long-lived biota diffusion equation will be:

$$\frac{dC_{LA}}{d_t} = \frac{1}{100}(C_{LA} - C_{LB}) + \cdots < other\ reservoirs >$$

These residence time constants are derived from observation and statistical data generated in recent decades. The complete list of the equations is generated in the same way for every reservoir in the diagram.

Every reservoir is considered to have zero carbon dioxide at the year 1850. The actual carbon dioxide concentration can be obtained by adding concentration at 1850 to the calculated increases.

The complete list of the seven carbon dioxide reservoirs interactions:

Lower atmosphere –

$$\frac{dC_{LA}}{d_t} = \frac{1}{\theta_{la-ua}}(C_{UA} - C_{LA}) + \frac{1}{\theta_{la-sb}}(C_{SB} - C_{LA}) + \frac{1}{\theta_{lb-la}}(C_{LB} - C_{LA}) + \frac{1}{\theta_{la-ul}}(C_{UL} - C_{LA}) + Q_c(t)$$

$$Q_c(t) = c_1 e^{r_1 t}$$

Short-lived biota

$$\frac{dC_{SB}}{d_t} = \frac{1}{\theta_{sb-la}}(C_{LA} - C_{SB})$$

Long-lived biota

$$\frac{dC_{LB}}{d_t} = \frac{1}{\theta_{lb-la}}(C_{LA} - C_{LB})$$

Ocean upper-layer

$$\frac{dC_{ul}}{d_t} = \frac{1}{\theta_{ul-la}}(C_{LA} - C_{UL}) + \frac{1}{\theta_{ul-dl}}(C_{DL} - C_{UL}) + \frac{1}{\theta_{ul-mb}}(C_{MB} - C_{UL})$$

Ocean Deep layer

$$\frac{dC_{dl}}{d_t} = \frac{1}{\theta_{dl-ul}}(C_{UL} - C_{DL})$$

Marine Biosphere

$$\frac{dC_{MB}}{d_t} = \frac{1}{\theta_{mb-ul}}(C_{UL} - C_{MB})$$

The very same reasoning is applied to the methane reservoirs. But methane is modeled to have fewer reservoirs compared to carbon dioxide. Methane will break down into different chemicals once it reaches the upper atmosphere and ceases to exist as methane. Only three reservoirs are considered: lower atmosphere, mixing layer and Deep Ocean. The simplification is due to the assumption that bio-organisms consume a minimal amount of methane in their life cycles.

The complete list of the three methane reservoirs interactions:

Lower Atmosphere

$$\frac{dM_{LA}}{d_t} = \frac{1}{\theta_{ml-la}}(M_{ML} - M_{LA}) + Q_M(t)$$

Ocean Mixing Layer

$$\frac{dM_{ML}}{d_t} = \frac{1}{\theta_{ml-la}}(M_{LA} - M_{ML})$$

Ocean Deep Layer

$$\frac{dM_{DO}}{d_t} = \frac{\mathbf{1}}{\theta_{ml-do}}(M_{ML} - M_{DO})$$

The input is a direct input into the lower atmosphere, and is modeled with the equation:

$$Q_c(t) = c_{\mathbf{1}}e^{r_{\mathbf{1}}t}$$

This equation is used to simulate the input into the lower atmosphere. The constant C_1 is solved for by setting the solution's output to known values. C_1 is selected so that at the year 2007, the concentration of carbon dioxide is approximately equal to 384ppm. A similar equation $Q_m(t)$ was used to model the methane situation, where the constant C_1 was set so that its concentration is about

The constant, r_1, is the greenhouse gases' rates of increase per year. Since the program is written in decadal increments, the values are multiplied by a factor of ten. The constant r_1 is set to have an initial value of 1% annual increase in the carbon dioxide model. Methane is believed to double its concentration within the next 100 years. So instead of assuming an arbitrary value, the rate of release was adjusted so that methane concentration will double in value from 2010 to 2100.

The concentration of green house gases in the atmosphere is calculated by the integration of these functions. These result in a function that will predict the carbon dioxide concentration in the atmosphere in part per million, and the concentration of methane in part per billion. The data for each decade from 1850 to 2100 is extrapolated from the resulting function. These data are then passed onto a second function that translate the atmospheric concentration into radiative forcing.

Radiative Forcing by Green House Gases

The concentration of the carbon dioxide and methane has been correlated with the temperature rise experienced in the past few centuries from recoded data as well as data obtained from exploring the ice cores. Recent advancements in science allowed scientist to study the energy retention properties of the green house gases.

NASA has generously provided a set of empirically formulated equations that relates the lower atmosphere concentration of each trace gas to their respective radiative forcing properties. These functions already accounts for several of the decomposition properties of the gases, and can be seen from the interrelationships of the three major trace gases.

Radiative forcing by carbon dioxide

$$F_{CO_2} = 4.841 \log\left(\frac{CO2_{YEAR}}{CO2_{1850}}\right) + 0.0906\left(\sqrt{CO2_{YEAR}} - \sqrt{CO2_{1850}}\right)$$

Radiative forcing by methane

$$F_{Ch_2} = 0.036\left(\sqrt{CH4_{YEAR}} - \sqrt{CH4_{1850}}\right) - aux(CH4_{YEAR}, NO_{1850}) - aux(CH4_{1850}, NO_{1850})$$

$$aux(CH4, NO) = 0.47 \log(1 + 2.01x10^{-5})(CH4 * NO)^{0.75} + 5.31x10^{-15} CH4(CH4 * NO)^{1.52}$$

Once again, the comparison is made to the year 1850, before any significant amount of trace gases were released into the atmosphere from the industrial growth across the globe. The concentrations of the three major gases are indicated as: 278 ppm, 700ppb, 270 ppb for carbon dioxide, methane, and nitrous oxide respectively.

Solar Irradiance Equation

See the solar irradiance section for explanation and evaluation:

$$C\frac{dT_m}{dt} = Q\{1 - A(T_m)\} - \sigma g(T_m){T_m}^4$$

Q is the solar radiation input and Tm is the global mean temperature. A(Tm) represents the earth's average albedo. σ is the Stefan-Boltzmann constant and g(Tm) is the grayness of the system. This "grayness" represents a deviation of black-body radiation. [31]

MATLAB Code

Main Script - model_main.m

```
%declare global variables for the entire model

%base year: 1850
%year increment: 10 yr
y_base = 1850;
y_inc = 10;
```

The model will allow 1850 to be the base year where CO2 and CH4, as the reference year and increase in decadal increments.

```
%calculated concentration
global co2_con ch4_con R_sun;

%Sun's output (W/m2)
R_sun = 343;
```

Concentrations of two major greenhouse gases, CO2 and CH4, as well as the sun's output are declared as global variables.

```
%Earth's surface area
%Only component facing the sun is accounted for
r = 300;
A_earth = 3.1416*r^2;
```

The equivalent surface area that is facing the sun at any point in time.

```
%call the script GHG to calculate the greenhouse gas
%   concentrations.
GHG;

fprintf('\n\n Year \tGHG absorbtion(W/m^2)\tSurface
temperature(K)');
```

The script GHG.m will load the CO2 and CH4 concentration in the atmosphere into the declared variables.

```
for i = 1:26
%
%Follow energy flow of the sun's rays:
%
%Incident ray reflected by clouds, and         incident on earth,
which is then reflected to the sky again.
E_earth(i) = E_abs(R_sun, i);

%With gas concentration, find the absorbed radiation by these gases
E_retATM(i) = ppmToRad(co2_con, ch4_con, i);
```

And iteration of 26 calls (1850 to 2100) will now convert the trace gases concentrations into combined radiative forcing and global mean temperature. The function ppmToRad will convert gas concentrations, from ppm or ppb, into radiative forcing expressed in W/m^2.

```
%Given gas concentration and incident radiation, find the surface
temperature increase.
Temp_sur(i)=0.329*E_retATM(i);
    fprintf('\n%5.0f%10.4f%30f%10.1f%10.3f%10.3f%10.4f\n',
y_base + y_inc*(i-1), E_retATM(i),Temp_sur(i));

end
```

The temperature is correlated the result of correlation of temperature data and trace gas concentrations.

fprintf('\n\ntemperture increase from 2010 to 2100:\t'); fprintf('%10.4f',Temp_sur(26)-Temp_sur(16)); fprintf('\n\n');	The difference between the present (2010) and 2100 is displayed.

Greenhouse gas generation - GHG.m

```
%Find the concentration of various greenhouse %gases in the
atmosphere.  Integrate and %solve for the differential equations for
CO2 %and CH4.
%
%solve DiffEQ
%   create co2_con and ch4_con arrays
%   conversion to be done in ppmTORad
%
% Initial condition
  y0=zeros(1,7);
  y1=zeros(1,3);
%
% Independent variable for ODE integration
  t0=1850;
  tf=2100;
  tout=[t0:10:tf]';
  nout=26;
  ncall=0;
  ncase=0;
%
% ODE itegration
  reltol=1.0e-06; abstol=1.0e-06;
  options=odeset('RelTol',reltol,'AbsTol',abstol);
  [t,y_c]=ode45 (@carbon,tout,y0,options);
  [t,y_m]=ode45 (@methane,tout,y1,options);
%
%display output
%
   fprintf('\n Year\tCO2_ppm \tCH4_ppb')
   %begins for loop, counter "it"
for it=1:nout
%
%   CO2 ppm (in lower atmosphere)
   co2_con(it) = 280*(1+y_c(it,1));
%
%   CH4 ppb (in lower atmosphere)
   ch4_con(it) = 812.5*(1+y_m(it,1));
%
%   Selected output
   fprintf('\n%5.0f%11.4f%15.4f%10.1f%10.3f%10.3f%10.4f\n',
t(it),co2_con(it),ch4_con(it));
end
```

This script integrated a two sets of differnential equations representing CO2 and CH4 concentration in the atmosphere. The equations are located in the files carbon.m and methan.m.

Assuming that the initial concentrations of the trace gases are zeros at 1850, the sets of equations all have an initial value of zero. The concentration at 1850 will be accounted for later.

Differential equations set-up procedures as needed for MatLab.

The concentrations of the two gases care stored into the arrays co2_con and ch4_con declared in the main script. The 1850 concentration is added onto the additional emission here as well.

Carbon Dioxide Differential Equations - carbon.m

<pre>function yt=carbon(t,y) % % Function carbon computes the temporal %derivatives of the seven dependent variables % % Parameters shared with other routines global ncall % % Model dependent variables cla=y(1); cua=y(2); csb=y(3); clb=y(4); cul=y(5); cdl=y(6); cmb=y(7); % % ODEs [c1,r1]=CO2_rate(t); dcla= 1/5*(cua-cla)+... 1/1*(csb-cla)+... 1/100*(clb-cla)+... 1/30*(cul-cla)+... c1*exp(r1*(t-1850)); dcua= 1/5*(cla-cua); dcsb= 1/1*(cla-csb); dclb= 1/100*(cla-clb); dcul= 1/30*(cla-cul)+... 1/100*(cdl-cul)+... 1/10*(cmb-cul); dcdl= 1/1000*(cul-cdl); dcmb= 1/10*(cul-cmb); % % Derivative vector yt(1)=dcla; yt(2)=dcua; yt(3)=dcsb; yt(4)=dclb; yt(5)=dcul; yt(6)=dcdl; yt(7)=dcmb; yt=yt'; % % Increment calls to model_1 ncall=ncall+1;</pre>	Carbon stores the seven differential equations that represents the seven reservoirs of carbon dioxide storage. This part of the model was lifted directly from an introductory Global CO2 model written by G.W. Griffiths (City University, London), A.J. McHugh (Lehigh University, USA) and W.E. Schiesser (University of Pennsylvania, USA). The model creates a sets of seven equations stored in the array 'y'. The seven reservoirs includes the lower atmosphere, the upper atmosphere, short and love live biota, and ocean upper, lower and mixed layers. These equations are created so that the concentrations of carbon dioxides moved from one reservoir to another by diffusion based on the concentration difference between adjacent reservoirs. Each of the gas' travel is impeded by what is known as residence time. The time that takes a mass of carbon to move from one reservoir to another. The longer the residence time, the longer it will take the carbon to travel out of a reservoir. For example, the residence time of a long lived biota, is about 100 years, such as a tree. Whereas agricultural crops will only last several months.

Methane Differential Equations – methane.m

function ym = methane(t, y) %Generate the atmospheric ppb of methane %methane is released into the atmosphere by %some rate as seen in the previous %researches. This model will provide a rate %of release into the lower atmosphere and %disperse into the upper atm and %the ocean. %The rate is given as the ppb emission per %decade, because the program work with %decadal increments. This rate is solved for %to give the ppb level of 2007 as a base %point. c_m1 = 8.0e-3; rate=0.012;	The methane model is model similar to the carbon dioxide equations presented previously. The methane model only have three reservoirs, as there does not seem to be significant amount of methane absorption in living organisms. The reservoirs include the lower atmospheres and the mixing and deep layers of the ocean.
% Model dependent variables m_la=y(1); m_ml=y(2); m_do=y(3); %ODE's %Three reservors : Lower Atm, Mixing layer, %Deep Ocean. only the ch4 in lower atm will %contribute, the other two reservoirs are %essentially storage. So only three %reservoirs	These constants are used to calibrate the model and they represent the methane input into the lower atmosphere by humans and nature. The model is calibrated against measured CH4 concentration at the year 2007, at 1761ppb. As according to our research, methane production is expected to double the CH4 concentration over the next century.
dm_la= 1/30*(m_ml-m_la)+... c_m1*exp(rate*(t-1850)); dm_ml= 1/1000*(m_la - m_ml); dm_do= 1/1000*(m_ml - m_do); % Derivative vector ym(1)=dm_la; ym(2)=dm_ml; ym(3)=dm_do; ym = ym';	The differential equations represent the travel of mass from one reservoir to another. Similarly, the residence time is used to impeded the travel of CH4 from one reservoir to another. The oceans is believe to sequester large amount of trace gases, and so a residence time of one millennia is chosen. The lower atmosphere get the most methane from natural sources such as melting permafrost and organic decay.

Translating Trace Gas Concentration to Radiative Forcing - ppmToRad.m

function power = ppmTOrad(co2, ch4, yr) %translate the ppm calcualted in methane and CO2 to W/m2 values %these are all based on equations from %IPCC climate change 2001 report %Original concentration of various gases %Carbon dioxide (ppm) %Methane (ppb) %Nitrous Oxide (ppb) Co = 278; Mo = 700; No = 270;	The original green houses gas concentrations with respect to the base year is needed for the calculations of radiative forcing.
%for carbon dioxide: % % F_co2 = 4.841*log(co2(yr)/Co)+ 0.0906*(sqrt(co2(yr)) - sqrt(Co)); %for methane: F_ch4 = 0.036*(sqrt(ch4(yr)) - sqrt(Mo)) - (f(ch4(yr),No) - f(Mo,No));	Two equations were written. One to represent carbon dioxide and another for methane. These equations were determined empirically by NASA.
power = F_co2 + F_ch4; function num = f(A, B) num = 0.47*log(1+(2.01E-5)*(A*B)^(0.75)+ (5.31E-15)*A*(A*B)^(1.52));	The sub function 'f' is needed as a mean to un clutter the methane function.

Changing The Carbon Dioxide Input - CO2_rate.m

```
function [c1,r1]=CO2_rate(t)
%
% Function CO2_rate returns the constants c1, % r1 in the CO2 source term
%
%   CO2_rate = c1*exp(r1*(t-1850))
%
% for the case ncase.
%
  global ncase;
%
% c1 sets the CO2 ppm at 2007
  c1=4.4e-03;
%
% Base CO2 rate
  r1b=0.01;
  r1c=0;
  r1=r1b;
%
%The equation of the CO2 dispersionrate into the lower atmosphere is
%  written here again for convineance. Not meant for operational use.
%
%  CO2_rate = c1*exp(r1*(t-1850));
%
%kyoto protocal
if(ncase==1)
   r1c=-0.0520; t_end=2020;    end
% decrease 30% emission in 50 years
if(ncase==2)
   r1c=-0.3000; t_end=2050;    end
% decrease 50% emission in 50 years
if(ncase==3)
   r1c=-0.5000; t_end=2050;    end
% base run, no changes
if(ncase==4)
   r1c= 0.0000;                end
% decrease 20% emission by 2030
if(ncase==5)
   r1c=-0.2000; t_end=2030;    end
% decrease 40% emission by 2030
if(ncase==6)
   r1c=-0.4000; t_end=2030;    end
% decrease 80% emission by 2050
if(ncase==7)
   r1c=-0.8000; t_end=2050;    end
%
% Change the base rate for t > 2010
  if(t>2010 && t<=t_end)
```

This function is used to modify the carbon dioxide input into the lower atmosphere. This can be used to simulate both human and natural input of carbon dioxide.

The function was used to calibrate the model so that the 2007 data point matches the recorded data. A base carbon dioxide rate is used to simulate human input.

The rate of carbon dioxide emissions is changed by multiplying a percentage over the next century. These numbers can be changed to simulate various actions taken by the humans.

Each case is as indicated by the accompanying comments. All the changes are expressed as percentages a and the period which the reduction would occur.

For example, for case number 3, a 50% reduction is simulated over 50 years.

The percentage change per decade is

`%Linear interpolation of the carbon emission rate in time between 2010 and 2100` `r1=r1b+(r1c*r1b)*(t-2010)/(t_end-2010);` `end` `%` `%After year end, the carbon dioxide concentrtaion will remain at the` `%reduced level indefinitly.` `%` `if (t>t_end)` `r1=r1b+r1b*r1c;` `end`	calculated by simple linear interpolation. Reduction is considered to be permanent at the end year, and the emission rate after the end year is set.

Energy Flow from Space - E_abs.m

`function powerRem = E_abs(incoming, i)` `%This function combine the clouds coverage and %reflectivity along with surface reflectivity %to produce the amount of radiation actually %absorbed by the earth.` `%get cloud albedo and coverage` `ps = 0.6605;` `a_cloud = 0.98;` `%` `%get mean surface albedo` `a_sur = 0.3;` `%combine reflected radiations from clouds and surface` `removed_r = ps*a_cloud + (1-ps)*a_sur;` `%total radiation reflected to space by clouds and surface` `rem = incoming - incoming*removed_r;` `%remaining radiation trapped on earth` `powerRem = incoming - rem;`	This function is used to account for the cloud coverage and surface reflectivity of the earth's surface. Combined effects of clouds and surface reflection removes large amount of energy from the surface. Average cloud coverage of the earth was calculated from the ISCCP. In this case, a cloud coverage of 66.05% was used. A mean surface reflectivity was given by our research. Effects of clouds and surface reflection is applied to the incoming sun ray, in order to calculate the actual energy absorbed by the earth. The energy is then radiated from the earth towards space though earth's atmosphere.

A second sets of code was written to accept multiple runs so that the program can plot up to seven scenarios at once on a graph. The second main script was written to run multiple scenarios at once, and plot and calculate the radiative forcing for each case. The results of the runs are attached in Appendix C. Appendix D is the augmented code that could run multiple cases at one program run.

```
% Modified main scrip to run multiple cases and display simulation results
% declare global variables for the entire model

%base year: 1850
%year increment: 10 yr
y_base = 1850;
y_inc = 10;
%define the time array for display purposes
y=[y_base:y_inc:y_base+y_inc*25];

global R_sun ncase;

%Sun's output (W/m2)
R_sun = 343;

%Earth's surface area
%Only component facing the sun is accounted for
r = 300;
A_earth = 3.1416*r^2;

% multiple simulation runs for comparison purposes.
% numcase is the number of cases to be simulated by the program
numcase = 7;
% begine loop to run through all cases in the program
for sim = 1:numcase
  % set the case number ncase to variable sim, so other parts of the
  % program can access and act according to the number ncase
  ncase = sim;
```

The gas concentrations are declared with in the iteration loop to catch the output of the GHG script.

```
  % receive the carbon dioxide and methane concentrations from the function
  % GHG.
  [co2_con, ch4_con]=GHG(sim);

  % display the scenario number on the screen
  fprintf('\n\nScenario Number:\t');
```

```
  fprintf('%10.4f\n',sim);

  %display title for display
  fprintf(' Year \t   GHG absorption\t  Surface temperature\t CO2 ppm\t    CH4 ppb');



  % calculate and display the energy retained in teh atmosphere, as well as
  % the temperature increase corresponding to the increase in GHG
  for it=1:26
   % calculate the energy retained by the GHG in the atmosphere
   E_retATM(it) = ppmToRad(co2_con, ch4_con, it);
```

A new results matrix is used to replace the two arrays, the matrix is arranged so that it will store each case's methane, carbon dioxide concentration, and the corresponding temperature increase.

```
   % store the simulation result into a two-dimensional matrix sorted by
   % case number and iteration number (years)
   result(it, sim) = 0.329*E_retATM(it);
   % display the results year by year
   fprintf('\n%5.0f%20.4f%20.4f%13.1f%17.3f%11.3f%10.4f\n',...
          y_base + y_inc*(it-1), E_retATM(it),result(it, sim), co2_con(it), ch4_con(it));
  end

  % find the difference in temperature between 2010 and 2100 for the current
  % case number.
  fprintf('\ntemperture increase from 2010 to 2100:\t');
  fprintf('%10.4f\n',result(26, sim)-result(17, sim));
end
```

A plot is created from the matrix, and display each case's temperature rise graphically. A legend is added to indicate the corresponding lines to the accompanying plans.

```
%
% Parametric plot
% plot results of all cases on one graph for a visual comparison.
  figure(2)
  plot(y,result(:,1),y,result(:,2),y,result(:,3),...
     y,result(:,4),y,result(:,5),y,result(:,6),...
     y, result(:,7))
```

```
axis([2000 2100 0.5 2]);

legend(   'r1 = Kyoto Protocol',...
        'r2 = 30% reduction by 2050',...
        'r3 = 50% reduction by 2050',...
        'r4 = no change',...
        'r5 = 20% reduction by 2030',...
        'r6 = 40% reduction by 2030',...
        'r7 = Barak Obama Stretegy',...
        'Location','NorthWest')

title(' Surface Temp Inc Caused by GHG VS. Time');
xlabel('Time (Year)'); ylabel('Surface Temperature Increase (deg C)');
```

Results/Analysis

MATLAB Model Results

The MATLAB model was used to simulate various human input scenarios. The computer outputs the surface temperature increase caused by trace gases in degree Celsius given the percent reduction from the present and the time period in which this reduction will be achieved. A modified version of the model has been created and will graph the effects that each reduction would have in comparison with the other scenarios.

First, without any reduction in thus human emissions and using data based on constants from the year 2007, the MATLAB predicts rise of 0.9315 °C in temperature by the year 2100. The Kyoto protocol is a legally binding agreement in which the countries that have agreed to it will reduce their collective emissions of greenhouse gases by 5.2% compared to their emissions in the year 1990. This reduction in emissions is expected to occur by 2012 and the goal is lower the emissions from six greenhouse gases, the main one being carbon dioxide. The model simulated the Kyoto protocol and yielded a 0.926°C increase, which is only a nominal 0.0787°C decrease over a non-modified human-input rate. According to our simulation, the Kyoto Protocol is an insufficient solution to the problem.

Although the protocol for lowering emissions is currently only 5.2% by the year 2030, it is very likely that the United Nations Framework Convention on Climate Change, who created the Kyoto Protocol, would likely implement more aggressive policies. More dramatic policies are assumed here for comparison purposes.

The first policy is the assumed a 30% emission reduction in 50 years, and shows a much more dramatic decrease compare to the current protocol. The simulation expected a 0.6575°C increase in temperature, which is a 0.3472°C decrease over the unperturbed case. The policy would cause a four times greater decrease in temperature by 2100. Reaching a 30% reduction in 50 years translates to a 6.2% decrease per decade, which is only a small amount greater than the 5.2% called for by the Kyoto Protocol.

In comparison, the 50% reduction over 50 years translated to a global temperature rise of 0.4327°C increase. This is a dramatic decrease over the unperturbed case of approximately 1°C of about 60%.

The environmental policy promised by President Barack Obama during his campaign claims an 80% reduction over the next 50 years. The policy would yield a 0.7140°C reduction compare to the base run, and causing only a 0.2860°C temperature increase by 2100. This reduction would rely on the chance that such aggressive policy can be implemented in the United States as well as across the globe.

The University of Yale conducted a research in 2007 that related the amount of carbon reduction to the growth of the national GDP for the United States. The two simulations were 20% carbon reduction by 2030, and 40% reduction by 2030. The result in this research serves to quantify the monetary cost of implementing emission reduction.

Without any reduction in emission, and with continuing growing trend of the economy at 2007, the U.S. GDP was expected to be 26,059 billion of USD in 2005 value. The value is given at its 2005 value, so that the inflation rate over the years is accounted for. In general, a growth is continued to be predicted, but only less than that of the unchanged scenario.

A 20% reduction in carbon release would cost the U.S. economy approximately 884 billion compared to the base line case, this though, would still mean a 2.2% increase from 2007. A temperature decrease of 0.2600°C from the base line model is expected. Under this scenario, this 0.26°C reduction would have an annual cost of 29.47 billion dollars over the thirty years. A one degree Celsius reduction would then cost 3,400 billion over the same time period.

The second scenario predicts a 40% decrease in carbon over the same 30 years would cause the GDP to slow to 0.17% over the 30 years. The reduction in emission translates to a 0.5494°C temperature increase at the year 2100, a 0.4553°C decrease from the baseline. The slowing in GDP growth is equivalent to a 2,868 billion decrease. The 0.4553°C would cost 95.60 billion every year for the thirty years that the policy is implemented.

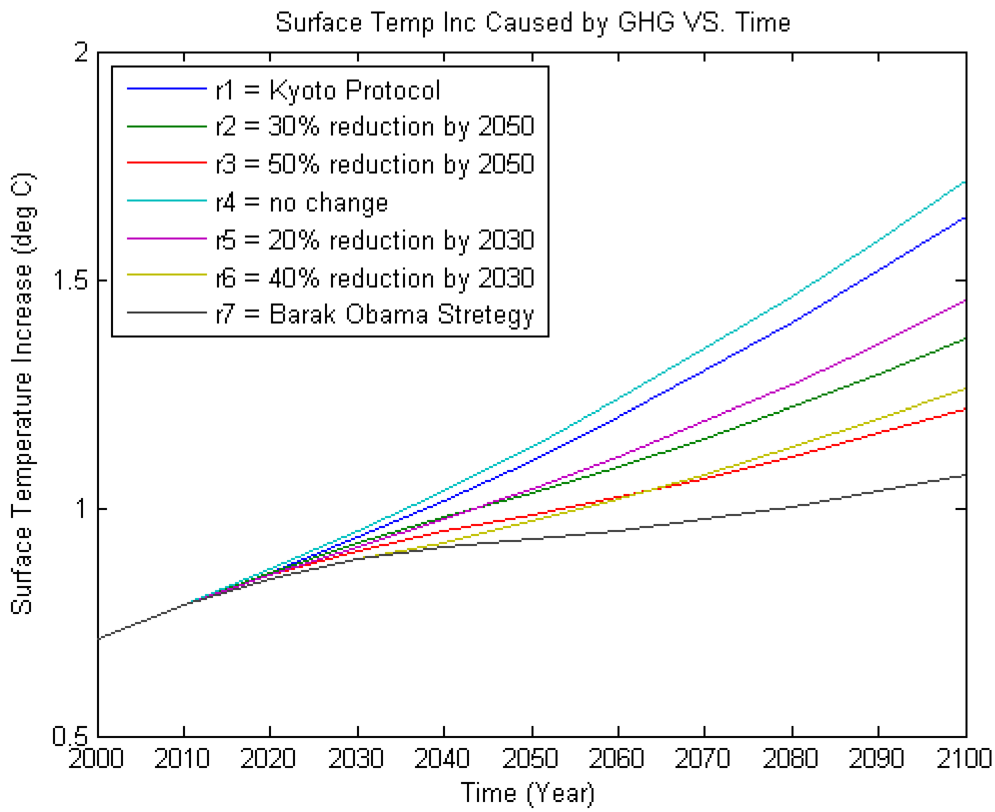


Figure 7 - Temperature Increase under Different Emission Scenarios

Figure 7 is the graphical representation of the scenarios mentioned above. What is worth noting is that a more moderate decrease over time would create similar effects in the long term. For example, a 40% reduction by 2030 produced similar result to a reduction of 50% by 2050. Given a longer period of time, this may cause less public backlashes during implementation. Moreover, a longer implementation time would allow the technology to be matured before field use and avoid less engineering faults to be made under pressure.

Relevance of Model Output to Crop Yield

The most direct effect of temperature increase on human lives would be the predicted crop yield reduction. Rather than having effects decades from the present, crop yield would be felt almost immediately by rising prices and general inflation of farm products.

Plants are believed to have a range of temperature at which the crop would be allowed to grow. Three zones of temperature have been identified to different plant growth range. There exist a minimal temperature for seed growth germination, rate of flowering and finally a period of grain filling for cercal. For each of the stages of plat growth, the rate of growth is a positive linear function between a base temperature and a optimal temperature, and beyond that, a negative linear function between the optimal temperature to a ceiling temperature [71].

According to recent articles, an annual temperature decrease of 0.50°C would cause a 0.45 ton decrease in wheat production per hectare. A 0.45 ton decrease means a 17.3% decrease compare to the 2.6ton per hectare yield that is usually produced [70]. Such predictions would mean that we are not passed that optimal growing temperature, and is currently heading into the negative linear region of crop yield.

The temperature difference computed by the model is translated into crop yield reduction, the results are shown in Figure 8. A reduction in food production is worsen by the expected population growth, which is expected to occur in less developed areas where less technologies are available to deal with famine.

	Scenario Number	Temperature Increase by 2100	Crop Yield Decrease %
Kyoto Protocol 5.2% by 2012	1	0.8528	32.97
30% reduction by 2050	2	0.5843	22.59
50% reduction by 2050	3	0.4327	16.73
Base Line	4	0.9315	36.02
20% reduction by 2030	5	0.6668	25.78
40% reduction by 2030	6	0.4762	18.41
Barak Obama 80% in 50 years	7	0.2860	11.06

Figure 8 - Crop Yield Reduction

Figure 8 shows the extent of the global warming problem in terms of crop yield. Even the most drastic changes would bring about an 11.06% decrease in crop yield. If nothing is done to minimize the effects of global warming, an approximate 40% of wheat production would be gone. On the other hand, a 30% reduction in 50 years would still be able to preserve about half of computed lost if nothing was done.

Conclusions

Global warming will create drastic and potentially deadly changes to human lives if left unaddressed. The natural effects of global warming have their roots in human activities, which released a tremendous amount of carbon dioxide, CFC and other environmentally harmful materials into the atmosphere. Although some natural sources of greenhouse gases are present, research indicates that human is a major contributor to the problem.

Since the industrial revolution, the thirst for production has created a great need for energy across the globe. Large parts of the world are still under heavy economically developments, and would continue to need more fuel and energy to promote the economic growth. However, many scientists believe that if such a trend is allowed, the earth will experience irreversible climate changes that would destroy the entire human civilization.

Throughout the project, many mitigation strategies were researched. These included new technology for renewable energy, modified crops to deal with the impending global heat, and regulations to reduce car emissions. After analyzing the various mitigation strategies,

A plan was created that would allow economic growth while controlling the global increase in temperature. The plan calls for a widespread use of readily available renewable resources, such as wind power, biofuels, and coal substitutes. According to the computer model, these plans would be able to reduce up to 60% of the temperature changes expected in the next century.

Recommendations

Due to time constraints, some key climate effects were left out of the MATLAB model. One such effect was how rising temperatures would influence the earth's water cycle. It is presumed that rising ocean temperatures would create more water vapor in the atmosphere. This additional water vapor would add to the residence time of water in the atmosphere. Today, the average residence time of water in the atmosphere is 9 days. It is yet to be seen how significant a rise in this time would be. With more water vapor in the atmosphere, there would be a possibility for an increase in cloud cover. It is important to realize that water vapor is the most predominate greenhouse gas and therefore, any fluctuations in its levels could have severe consequences. To model this increase in water vapor would improve our model substantially. One possible method of adding this component to the model would be by using the following evaporation equation:

$$E_{os} = \frac{\rho_a}{\rho_o} C_{lh} W_s \left(q_{os} - q_a\right)$$

This equation is based on the specific humidity equations that are in Adrian Gill's *Atmosphere-Ocean Dynamics*. [32]

Another important addition to the model would be the introduction of other greenhouse gases such as nitrous oxide and CFCs. Although these gases have a much lower radiative forcing, they still do contribute towards global warming. Modeling these gases would provide a more precise, and, unfortunately, a bleaker estimate of the global warming to come.

The always imminent population growth is another factor that could be introduced to the model. It is predicted that in the next 50 years, the world's population will double. Such a drastic growth will most likely impede on the emission regulations that will have been established. Modeling this increase would offer a note worthy insight into the effects that population growth has on global warming and greenhouse gas emissions in general.

Bibliography

1. "20% Wind Energy by 2030." U.S. Department of Energy. 2008. DOE/GO-102008-2567. Washington, DC. <http://www.20percentwind.org/20percent_Summary_Presentation.pdf>

2. Akbari, Hashem, Surabi Menon, and Arthur Rosenfeld. Global Cooling: Increasing World-wide Urban Albedos to Offset CO2. Rep. 2008.

3. "Algenol Biofuels - Contact Us." Algenol Biofuels - Harnessing the Sun to Fuel the World. 03 Mar. 2009 <http://www.algenolbiofuels.com/contactus.html>.

4. Amen, Ahava, A Gift from New Earth <http://www.newearth1.net/downloads/NewEarth_Gift_Article.pdf>

5. Anderson, Philip W. "Cosmic Rays." 28 Jan. 2009. NASA. <http://helios.gsfc.nasa.gov/cosmic.html>

6. Bensinger, Ken and Tankersley, Jim. Los Angeles Times: "Obama Moves To Force Automakers To Produce More Fuel-Efficient Vehicles." 27 Jan 2009, <http://www.latimes.com/business/la-fi-emissions27-2009jan27,0,90848.story>

7. Borenstein, Seth; "Scientists Find New Global Warming 'Time Bomb'" <http://www.thewe.cc/weplanet/news/arctic/permafrost_melting.htm>

8. Bourassa M.A., Maue, R.N., Smith, R.N. "Ocean Winds" (Climate 2007), pg. 32

9. "Campaign 2008." Tech + Lifestyle: Enhance your World 15 SEP 2005 16 Feb 2009 <http://techpluslifestyle.wordpress.com/2008/09/17/campaign-2008/>.

10. "Carbon Dioxide Emissions from the Generation of Electric Power in the United States", July 2002, Department of Energy <http://www.eia.doe.gov/cneaf/electricity/page/co2_report/co2report.html#electric>

11. "Carbon regulation could hit 1 mn US firms." India Times 16 Sep 2008 22 Sep 2008 <http://timesofindia.indiatimes.com/Global_Warming/Carbon_regulation_could_hit_1_mn_US_firms/articleshow/3487671.cms>.

12. Carslaw, K. G., R. G. Harrison, and J. Kirkby. "Cosmic Rays, Clouds, and Climate." Science 298 (2002): 1732-737.

13. Centre for International Climate and Environmental Research (CICERO). "Cosmic Rays Do Not Explain Global Warming, Study Finds." ScienceDaily 17 December 2008. 15 February 2009< http://www.sciencedaily.com- /releases/2008/12/081217075138.htm>

14. Center for Liquefied Natural Gas. 03 Mar. 2009 <http://www.lngfacts.org/>.

15. Chang, Kenneth. “Scientists Would Turn Greenhouse Gasses Into Gassoline.” 2008, <http://www.nytimes.com/2008/02/19/science/19carb.html>

16. China Energy Research Institute, National Institute for Environmental Studies Reports: <http://www.env.go.jp/en/wpaper/1995/eae240096000001.gif>

17. "Clouds & Radiation Fact Sheet : Feature Articles." NASA Earth Observatory: Home. <http://earthobservatory.nasa.gov/Features/Clouds/clouds.php>.

18. "Clouds & Radiation Fact Sheet : Feature Articles." NASA Earth Observatory: Home. <http://earthobservatory.nasa.gov/Features/Clouds/clouds3.php>.

19. "Clouds & Radiation Fact Sheet : Feature Articles." NASA Earth Observatory: Home. 03 Mar. 2009 <http://earthobservatory.nasa.gov/Features/Clouds/clouds4.php>.

20. Danielo, Olivier. "An algae-based fuel." Biofuture. 255 (2005).

21. Davidson, Paul. “Utilities shrink the role of coal.” (pg. 4B) September 22, 2008, USA Today

22. Dlugokencky, E., Schnell, R.C.; Methane (Climate 2007); pg 27

23. Dutton, G.S., Elkins, J.W. “ Nitrous Oxide and Sulfur Hexafluoride.” (Climate 2007); pg. 30

24. "Earth Global Monitoring Division." NOAA Earth System Research Laboratory. 03 Mar. 2009 <http://www.esrl.noaa.gov/gmd/>.

25. Edward A. G. Schuur Vulnerability of Permafrost Carbon to Climate Change: Implications for the Global Carbon Cycle. BioScience, September 2008 / Vol. 58 No. 8

26. "Envocare: Liquefied Petroleum Gas (LPG), Liquefied Natural Gas (LNG) and Compressed Natural Gas (CNG)." Envocare: Environment, Recycling, Ethical Investment, Alternative Energy. 03 Mar. 2009 <http://www.envocare.co.uk/lpg_lng_cng.htm>.

27. Fan, Liang-Shih, and Raja A. Jadhav. "Clean Coal Technologies: OSCAR and CARBONOX Commercial Demonstrations." The American Institute of Chemical Engineers Journal 48 (2002): 2115-123.

28. Feely R.A., Sabine C.L., Wanninkhof R. , Takahashi T.; Global ocean carbon cycle (Climate 2007); pg. 52

29. Fields, C.B, p. 373, Diverse Controls on Carbon Storage under Elevated CO2, 1999 Academic Press London

30. Forest Carbon-Sink Potential Explored (May 1999) CNN.com <http://www.cnn.com/NATURE/9905/14/tree.growth.enn/index.htm>

31. Ghil, Michael. "Topics in Geophysical Fluid Dynamics." Springer-Verlag (1987): 302-303

32. Gill, Adrian E. Atmosphere-Ocean Dynamics. New York: Academic P, 1982.

33. Hamwey, Robert. "Active Amplification of the Terrestrial Albedo to Mitigate Climate Change: An Exploratory Study." Mitigation and Adaptation Strategies for Global Change 19 DEC 2005 1-21. 16 Feb 2009 <http://arxiv.org/ftp/physics/papers/0512/0512170.pdf>.

34. Hulsey, Brett, Pg. 10, Ethanol: A Convenient Solution to an Inconvenient Truth, December 2007

35. Humi, Mayer. Modeling Geophysical Flow, pg. 3

36. Josek, Fred. "Potential energy and greenhouse gas emission effects of hydrogen production from coke oven gas in U.S. steel mills." 28 Jan 2008, <http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V3F-4RPD799-1&_user=74021&_rdoc=1&_fmt=&_orig=search&_sort=d&view=c&_acct=C000005878&_version=1&_urlVersion=0&_userid=74021&md5=1d63b2b1893842c83abd8352541ee12a)>

37. Kahn, Michael. "Sun-reflecting crops could ease global warming." Reuters 15 JAN 2009 15 Feb 2009 <http://www.reuters.com/article/environmentNews/idUSTRE50E5P920090115>.

38. Kenworth Truck Company Press Releases. "Kenworth to Produce Liquefied Natural Gas Vehicles; Westport Innovations to Supply LNG System." 24 Jan 2008, <http://www.kenworth.com/6100_pre_mor.asp?file=2255>

39. Knutti, Reto. "Hotter or not? Should we believe model predictions of future climate change?." Significance 5DEC 2008 159-162. 15 Feb 2009 <http://www.ingentaconnect.com/bpl/sign/2008/00000005/00000004/art00004>.

40. "Kyoto Protocol." 26 Feb 2009 <http://www.kyotoprotocol.com/>.

41. Martin, Jeffrey F. and Kubic William L Jr. "Green Freedom." 2007, <http://www.lanl.gov/news/newsbulletin/pdf/Green_Freedom_Overview.pdf>

42. Martinelli, Nicole; Generating Power From Kites; <http://www.wired.com/science/discoveries/news/2006/10/71908>; October 10, 2006

43. "Masked Global Warming During the Past 20 Years." Science Daily. 28 November 2001. 18 September 2008 <http://www.sciencedaily.com/releases/2001/11/011128035329.htm>.

44. McGee, Kenneth. "Impacts of Volcanic Gases on Climate, the Environment, and People." May 1997. <http://pubs.usgs.gov/of/1997/of97-262.html.>

45. Melting of permafrost could trigger rapid global warming warns UN, mongabay.com, February 21, 2008.<http://news.mongabay.com/2008/0221-methane.html>

46. Montzka, S.A., Schnell, R.C.; Halocarbons (Climate 2007); pg 28

47. Morgan, James. "Ocean climate fix remains afloat." BBC News 29 Jan. 2009. <http://news.bbc.co.uk/2/hi/science/nature/7856144.htm>.

48. Nelson, Bob. "Willson: The Sun May Be Factor in Global Warmup." Columbia University: Record 23 (1997).

49. Ornstein, Peter. "Fighting hunger with flood-tolerant rice." CNN 2009 15 Feb 2009 <http://www.cnn.com/2009/TECH/science/01/29/waterproof.rice/>.

50. Quantum Dots May Lead to Rainbow Solar Cells, PhysOrg.com, March 2008 <http://www.physorg.com/news124111555.html>

51. Repetto , Robert. "How Greenhouse Gas Emissions will Effect the American Economy." Yale University 2007 22 Sep 2008 <http://www.climate.yale.edu/seeforyourself/>.

52. Roach, John, Studies Measures Capacity of “Carbon Sinks” (June 2001), National Geographic News <http://news.nationalgeographic.com/news/2001/06/0621_carbonsinks.html>

53. Rogers, H. H., p. 217, Response of Plants to Elevated Atmospheric Co2, 1999 Academic Press London

54. Rosengren, Paul, Joint Venture Announced to Market and Deploy Next Generation Compressed Air Energy Storage (CAES) Plants , August 2008, <http://www.pseg.com/media_center/pressreleases/articles/2008/2008-08-26.jsp>

55. Rutgers, The State University of New Jersey. “Pinatubo Volcano Research Boosts Case for Human-Caused Global Warming.” ScienceDaily. 21 February 2002. 18 September 2008< http://www.sciencedaily.com/releases/2002/02/020220075850.htm.>

56. Sage, R.F, p. 289-290, Implications of Stress in Low CO2 Atmosphere of the Past, Carbon Dioxide and Environmental Stress, 1999 Academic Press London

57. Scafetta, Nicola, and Bruce J. West. "Is climate sensitive to solar variability?" Physics Today (2008): 50-51.

58. Schiermeier , Quirin , Trees don't suck up carbon dioxide as hoped (August 2005) Nature News,<http://www.nature.com/news/2005/050825/full/news050822-7.html>

59. Schiermeier, Quirin, Arctic Water Flow Speeding Up, April 6, 2006

60. Schnell, R.C.; Trace gases and aerosols (Climate 2007); pg 26

61. Schuur, Ted, Permafrost Carbon and Climate Feedback

62. Scientists Map Out “Dream Storage” For CO2, Madrigal, Alexis, (July 2008) WIRED Science. <http://blog.wired.com/wiredscience/2008/07/scientists-map.html>

63. Shimbun, sahi , Beating the Heat Island Effect, August 2008, Asahi News <http://www.asahi.com/english/Herald-asahi/TKY200808050072.html>

64. Simpler way to counter global warming explained: Lock up carbon in soil and use bioenergy exhaust gases for energy, Lang, Susan (May 2007) Cornell University – Chronicle Online <http://www.news.cornell.edu/stories/May07/biochar.climate.ssl.html>

65. “SlurryCarb Process.” EnerTech. 03 Mar. 2009 <http://www.enertech.com/technology/slurrycarb_process.html>.

66. Stern, Nicholas. Stern Review on the Economics of Climate Change. Rep. 2006.

67. Subsurface carbon inventory (Climate 2007); pg. 54

68. Taylor F.W. pg. 109 Elementary Climate Physics.2005

69. "The Hydrologic Cycle." PhysicalGeography.net Welcome Page. <http://www.physicalgeography.net/fundamentals/8b.html>.

70. The New Dawn of Solar, Popular Science, December 2007 <http://www.popsci.com/popsci/flat/bown/2007/green/item_59.html>

71. The New Dawn of Solar; The Third Wave, (2008) Nanosolar <http://www.nanosolar.com/rollprocessing.htm>

72. The Ocean Carbon Cycle (Nov. –Dec. 2002) Harvard Magazine, retrieved Sept 2008 <http://harvardmagazine.com/2002/11/the-ocean-carbon-cycle.html>

73. Trees and Vegetation, (October 2007) United States Enviromental Protection Agency <http://www.epa.gov/hiri/strategies/vegetation.html>

74. US Department of Energy: Energy Efficiency and Renewable Energy. "Fuel Cell Vehicles." 2009, <http://www.afdc.energy.gov/afdc/vehicles/fuel_cell.html>

75. US Environmental Protection Agency. "Mobile Air Conditioning." 19 Feb 2009, <http://www.epa.gov/cppd/mac/>

76. Vital Ocean 'Carbon Sink' Nearly Full, (May, 2007) Discovery Channel, retrieved Sept. 2008 <http://dsc.discovery.com/news/2007/05/17/southernocean_pla.html?category=earth>

77. Waple, Anne M. "The sun-climate relationship in recent centuries: a review." Progress in Physical Geography 23 (1999): 309-28.

78. West, Peter, NOAA News Online(Story 2412), March 31st, 2005 <http://www.noaanews.noaa.gov/stories2005/s2412.htm>

79. Wheat yield on decline due to temperature rise. <http://www.thaindian.com/newsportal/business/wheat-yield-on-decline-due-to-temperature-rise_10068260.html.>

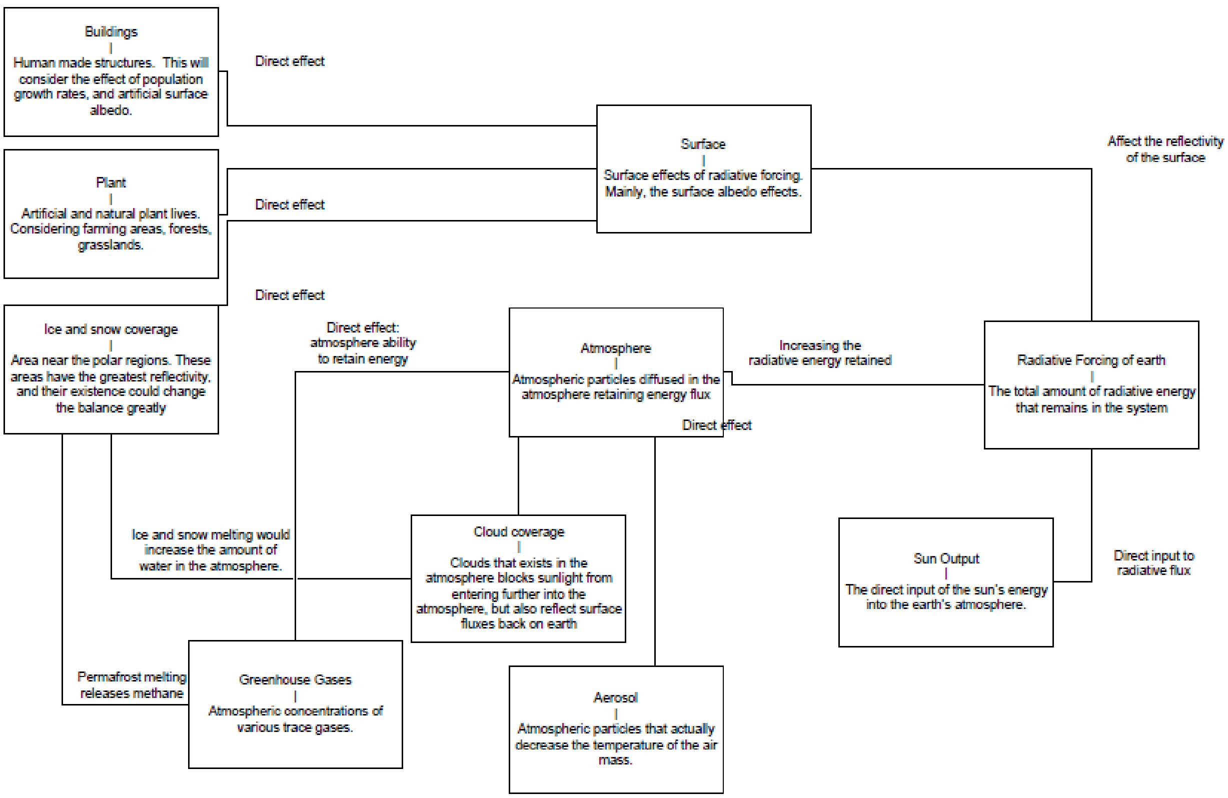
80. Wheeler, Timothy R.. Temperature variability and the yield of annual crops. Pg. 1. Agriculture, Ecosystems and Environment 82 (2000) 159–167

81. Willson, Richard C., and Alexander V. Mordvinov. "Secular total solar irradiance trend during solar cycles 21-23." Geophysical Research Letters 30 (2003): 3.1-3.4.

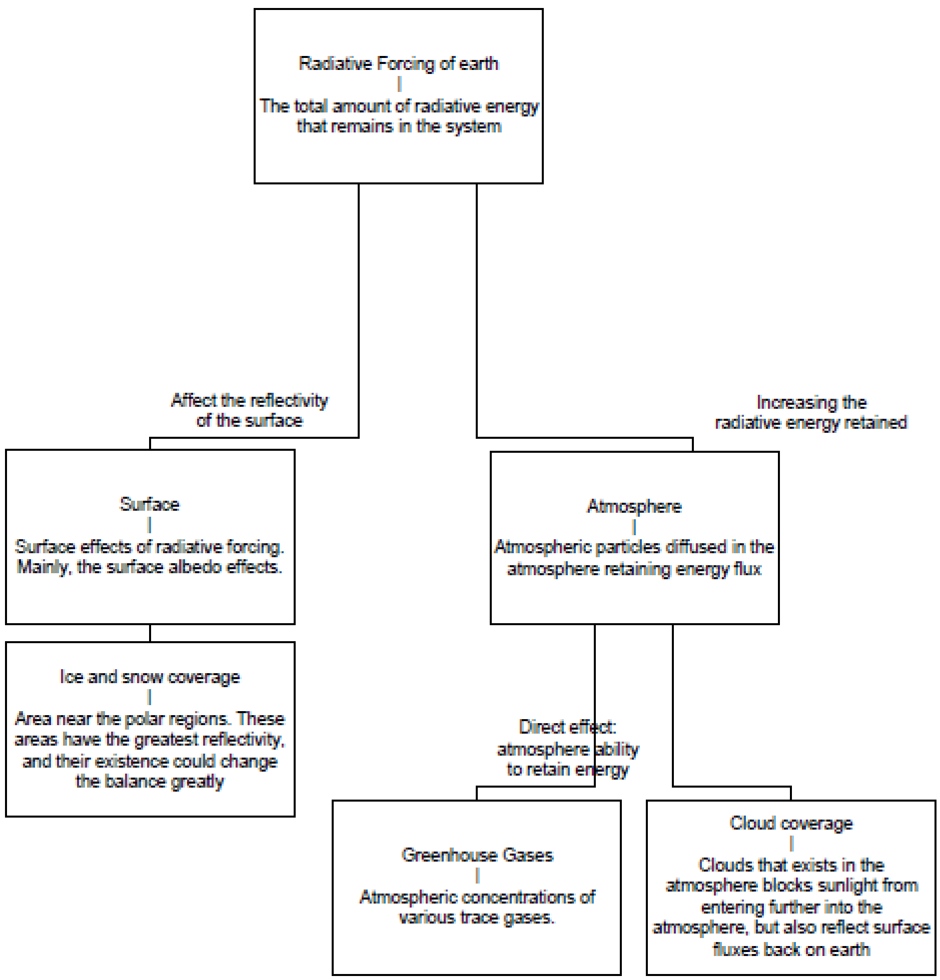
82. Yacobucci, Brent D. CRS Report For Congress: “Regulation of Vehicle Greenhouse Gas Emissions: State and Federal Standards.” 11 Jan 2008, <http://www.usembassy.at/en/download/pdf/regulation_ghg.pdf>

Appendices

Appendix A



Appendix B



Radiative Forcing of earth
|
The total amount of radiative energy that remains in the system
Affect the reflectivity of the surface
Increasing the radiative energy retained
Surface
|
Surface effects of radiative forcing. Mainly, the surface albedo effects.
Atmosphere
|
Atmospheric particles diffused in the atmosphere retaining energy flux
Ice and snow coverage
|
Area near the polar regions. These areas have the greatest reflectivity, and their existence could change the balance greatly
Direct effect: atmosphere ability to retain energy
Greenhouse Gases
|
Atmospheric concentrations of various trace gases.
Cloud coverage
|
Clouds that exists in the atmosphere blocks sunlight from entering further into the atmosphere, but also reflect surface fluxes back on earth

Appendix C

Scenario Number: 1.0000

Year	GHG absorption	Surface temperature	CO2 ppm	CH4 ppb
1850	0.1053	0.0346	280.0	812.500
1860	0.2314	0.0761	284.7	871.457
1870	0.3356	0.1104	288.7	921.382
1880	0.4370	0.1438	292.8	965.934
1890	0.5390	0.1773	297.0	1007.837
1900	0.6441	0.2119	301.5	1049.175
1910	0.7540	0.2481	306.3	1091.593
1920	0.8703	0.2863	311.6	1136.446
1930	0.9943	0.3271	317.2	1184.908
1940	1.1271	0.3708	323.4	1238.053
1950	1.2699	0.4178	330.1	1296.913
1960	1.4237	0.4684	337.5	1362.524
1970	1.5894	0.5229	345.6	1435.965
1980	1.7680	0.5817	354.5	1518.392
1990	1.9604	0.6450	364.3	1611.059
2000	2.1674	0.7131	375.1	1715.349
2010	2.3900	0.7863	387.0	1832.801
2020	2.6126	0.8595	399.0	1965.132
2030	2.8430	0.9353	411.6	2114.267
2040	3.0920	1.0173	425.6	2282.367
2050	3.3592	1.1052	441.1	2471.866
2060	3.6449	1.1992	458.1	2685.501
2070	3.9495	1.2994	476.9	2926.356
2080	4.2736	1.4060	497.6	3197.907
2090	4.6176	1.5192	520.3	3504.072
2100	4.9821	1.6391	545.3	3849.265

temperature increase from 2010 to 2100: 0.8528

Scenario Number: 2.0000

Year	GHG absorption	Surface temperature	CO2 ppm	CH4 ppb
1850	0.1053	0.0346	280.0	812.500
1860	0.2314	0.0761	284.7	871.457
1870	0.3356	0.1104	288.7	921.382
1880	0.4370	0.1438	292.8	965.934
1890	0.5390	0.1773	297.0	1007.837
1900	0.6441	0.2119	301.5	1049.175
1910	0.7540	0.2481	306.3	1091.593
1920	0.8703	0.2863	311.6	1136.446
1930	0.9943	0.3271	317.2	1184.908
1940	1.1271	0.3708	323.4	1238.053
1950	1.2699	0.4178	330.1	1296.913
1960	1.4237	0.4684	337.5	1362.524
1970	1.5894	0.5229	345.6	1435.965
1980	1.7680	0.5817	354.5	1518.392
1990	1.9604	0.6450	364.3	1611.059
2000	2.1674	0.7131	375.1	1715.349
2010	2.3900	0.7863	387.0	1832.801
2020	2.6057	0.8573	398.5	1965.132
2030	2.8022	0.9219	408.7	2114.267
2040	2.9819	0.9810	417.6	2282.367
2050	3.1458	1.0350	425.1	2471.866
2060	3.3163	1.0911	432.9	2685.501
2070	3.5050	1.1531	441.8	2926.356
2080	3.7098	1.2205	451.7	3197.907
2090	3.9301	1.2930	462.6	3504.072
2100	4.1659	1.3706	474.5	3849.265

temperature increase from 2010 to 2100: 0.5843

Scenario Number: 3.0000

Year	GHG absorption	Surface temperature	CO2 ppm	CH4 ppb
1850	0.1053	0.0346	280.0	812.500
1860	0.2314	0.0761	284.7	871.457
1870	0.3356	0.1104	288.7	921.382
1880	0.4370	0.1438	292.8	965.934
1890	0.5390	0.1773	297.0	1007.837
1900	0.6441	0.2119	301.5	1049.175
1910	0.7540	0.2481	306.3	1091.593
1920	0.8703	0.2863	311.6	1136.446
1930	0.9943	0.3271	317.2	1184.908
1940	1.1271	0.3708	323.4	1238.053
1950	1.2699	0.4178	330.1	1296.913
1960	1.4237	0.4684	337.5	1362.524
1970	1.5894	0.5229	345.6	1435.965
1980	1.7680	0.5817	354.5	1518.392
1990	1.9604	0.6450	364.3	1611.059
2000	2.1674	0.7131	375.1	1715.349
2010	2.3900	0.7863	387.0	1832.801
2020	2.5914	0.8526	397.5	1965.132
2030	2.7547	0.9063	405.3	2114.267
2040	2.8879	0.9501	410.8	2282.367
2050	2.9965	0.9858	414.2	2471.866
2060	3.1088	1.0228	417.6	2685.501
2070	3.2379	1.0653	421.9	2926.356
2080	3.3809	1.1123	426.8	3197.907
2090	3.5368	1.1636	432.2	3504.072
2100	3.7052	1.2190	438.3	3849.265

temperature increase from 2010 to 2100: 0.4327

Scenario Number: 4.0000

Year	GHG absorption	Surface temperature	CO2 ppm	CH4 ppb
1850	0.1053	0.0346	280.0	812.500
1860	0.2314	0.0761	284.7	871.457
1870	0.3356	0.1104	288.7	921.382
1880	0.4370	0.1438	292.8	965.934
1890	0.5390	0.1773	297.0	1007.837
1900	0.6441	0.2119	301.5	1049.175
1910	0.7540	0.2481	306.3	1091.593
1920	0.8703	0.2863	311.6	1136.446
1930	0.9943	0.3271	317.2	1184.908
1940	1.1271	0.3708	323.4	1238.053
1950	1.2699	0.4178	330.1	1296.913
1960	1.4237	0.4684	337.5	1362.524
1970	1.5894	0.5229	345.6	1435.965
1980	1.7680	0.5817	354.5	1518.392
1990	1.9604	0.6450	364.3	1611.059
2000	2.1674	0.7131	375.1	1715.349
2010	2.3900	0.7863	387.0	1832.801
2020	2.6289	0.8649	400.2	1965.132
2030	2.8850	0.9492	414.6	2114.267
2040	3.1591	1.0393	430.6	2282.367
2050	3.4519	1.1357	448.2	2471.866
2060	3.7643	1.2384	467.6	2685.501
2070	4.0967	1.3478	489.1	2926.356
2080	4.4500	1.4640	512.8	3197.907
2090	4.8247	1.5873	539.0	3504.072
2100	5.2213	1.7178	567.9	3849.265

temperature increase from 2010 to 2100: 0.9315

Scenario Number: 5.0000

Year	GHG absorption	Surface temperature	CO2 ppm	CH4 ppb
1850	0.1053	0.0346	280.0	812.500
1860	0.2314	0.0761	284.7	871.457
1870	0.3356	0.1104	288.7	921.382
1880	0.4370	0.1438	292.8	965.934
1890	0.5390	0.1773	297.0	1007.837
1900	0.6441	0.2119	301.5	1049.175
1910	0.7540	0.2481	306.3	1091.593
1920	0.8703	0.2863	311.6	1136.446
1930	0.9943	0.3271	317.2	1184.908
1940	1.1271	0.3708	323.4	1238.053
1950	1.2699	0.4178	330.1	1296.913
1960	1.4237	0.4684	337.5	1362.524
1970	1.5894	0.5229	345.6	1435.965
1980	1.7680	0.5817	354.5	1518.392
1990	1.9604	0.6450	364.3	1611.059
2000	2.1674	0.7131	375.1	1715.349
2010	2.3900	0.7863	387.0	1832.801
2020	2.5984	0.8549	398.0	1965.132
2030	2.7778	0.9139	407.0	2114.267
2040	2.9602	0.9739	416.0	2282.367
2050	3.1616	1.0402	426.3	2471.866
2060	3.3797	1.1119	437.7	2685.501
2070	3.6142	1.1891	450.2	2926.356
2080	3.8651	1.2716	463.9	3197.907
2090	4.1326	1.3596	478.9	3504.072
2100	4.4168	1.4531	495.3	3849.265

temperature increase from 2010 to 2100: 0.6668

Scenario Number: 6.0000

Year	GHG absorption	Surface temperature	CO2 ppm	CH4 ppb
1850	0.1053	0.0346	280.0	812.500
1860	0.2314	0.0761	284.7	871.457
1870	0.3356	0.1104	288.7	921.382
1880	0.4370	0.1438	292.8	965.934
1890	0.5390	0.1773	297.0	1007.837
1900	0.6441	0.2119	301.5	1049.175
1910	0.7540	0.2481	306.3	1091.593
1920	0.8703	0.2863	311.6	1136.446
1930	0.9943	0.3271	317.2	1184.908
1940	1.1271	0.3708	323.4	1238.053
1950	1.2699	0.4178	330.1	1296.913
1960	1.4237	0.4684	337.5	1362.524
1970	1.5894	0.5229	345.6	1435.965
1980	1.7680	0.5817	354.5	1518.392
1990	1.9604	0.6450	364.3	1611.059
2000	2.1674	0.7131	375.1	1715.349
2010	2.3899	0.7863	387.0	1832.801
2020	2.5713	0.8460	396.2	1965.132
2030	2.6931	0.8860	401.0	2114.267
2040	2.8112	0.9249	405.4	2282.367
2050	2.9478	0.9698	410.8	2471.866
2060	3.0991	1.0196	416.9	2685.501
2070	3.2640	1.0739	423.8	2926.356
2080	3.4422	1.1325	431.3	3197.907
2090	3.6333	1.1954	439.5	3504.072
2100	3.8372	1.2625	448.4	3849.265

temperature increase from 2010 to 2100: 0.4762

Scenario Number: 7.0000

Year	GHG absorption	Surface temperature	CO2 ppm	CH4 ppb
1850	0.1053	0.0346	280.0	812.500
1860	0.2314	0.0761	284.7	871.457
1870	0.3356	0.1104	288.7	921.382
1880	0.4370	0.1438	292.8	965.934
1890	0.5390	0.1773	297.0	1007.837
1900	0.6441	0.2119	301.5	1049.175
1910	0.7540	0.2481	306.3	1091.593
1920	0.8703	0.2863	311.6	1136.446
1930	0.9943	0.3271	317.2	1184.908
1940	1.1271	0.3708	323.4	1238.053
1950	1.2699	0.4178	330.1	1296.913
1960	1.4237	0.4684	337.5	1362.524
1970	1.5894	0.5229	345.6	1435.965
1980	1.7680	0.5817	354.5	1518.392
1990	1.9604	0.6450	364.3	1611.059
2000	2.1674	0.7131	375.1	1715.349
2010	2.3899	0.7863	387.0	1832.801
2020	2.5713	0.8460	396.2	1965.132
2030	2.6932	0.8860	401.0	2114.267
2040	2.7750	0.9130	402.8	2282.367
2050	2.8305	0.9312	402.5	2471.866
2060	2.8901	0.9508	402.0	2685.501
2070	2.9650	0.9755	402.3	2926.356
2080	3.0523	1.0042	403.1	3197.907
2090	3.1506	1.0365	404.2	3504.072
2100	3.2592	1.0723	405.7	3849.265

temperature increase from 2010 to 2100: 0.2860