COMINO FOUNDATION

The Earth's Temperature and Global Warming

The age of the Earth is said to be over 4½ billion years with the oldest rocks discovered having an age of about 3.8billion years. Over this time the Earth has passed through various geological periods that have been shaped solely by our solar system.

Mankind is fortunate that planet Earth has just the right position in the solar system to allow an atmosphere that enables life to exist and thrive. But the comfortable, temperate environment which exists across the world today, and has allowed mankind to evolve over the last 10,000 years, exists because the Earth is in an interglacial period, which is a favourable point in the established climatic cycle.

Scientists have observed that the temperature of the world is increasing at a faster rate than would be expected under the natural progress of changes to the climate of the world. How this is being caused, the extent of the temperature increase and its potential impact on mankind are causing international concern. The consensus view of nearly all climate scientists is that current global warming is caused by human activity releasing gases caused by the use of fossil fuels, the conversion of forests to agricultural land and increased livestock. If this is the cause, the major issue of the 21st century, after population growth, is for mankind to eliminate the gas emissions caused by human activity, stabilise global warming and preserve the Earth's current environment for future generations.

The big picture

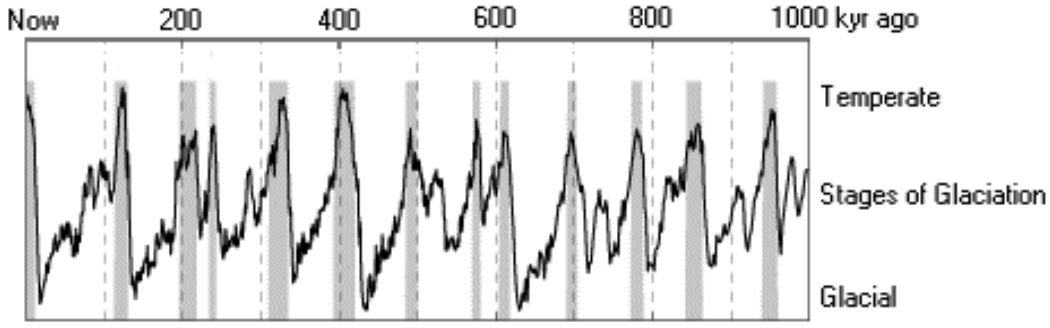
Looking at the Earth's planetary neighbours Venus is closer to the Sun and is so hot that its surface would melt lead. Mars is further from the Sun and its winters are so cold that steel on its surface would shatter. The position of the Earth in relation to the Sun is critical to its temperature.

The orbital characteristics of the Earth around the Sun, however, are not constant and the variations, which occur gradually over thousands of years, cause the climate of the world to change significantly. The most important cyclical variation is the shape of the orbit around the Sun. Over approximately 100,000 years the orbit changes from being nearly circular to being more elliptical. The annual change in the distance of the Earth from the Sun is only 3% when nearly circular, as at present, and 9% when most elliptical. As a result the amount of energy received from the Sun, which drives climate conditions, varies by 7% and 20% respectively. When the orbit is elliptical the length of winter and summer increases.

The second cyclical variation is that like a wobbling top the orientation of the Earth's axis is slowly but continually changing so that it traces out a conical shape in a cycle of approximately 26,000 years. The practical impact of this cycle is to slightly change the timing of winter and summer solstices. The third cyclical variation relates to the tilt of the Earth which can vary over 41,000 years between 22.5^0 and 24.5^0. It is currently 23.5^0 and decreasing. When the tilt is at its smallest there is less variation between summer and winter which favours increased snowfall and reduced melting of glaciers, the net effect of which is more formation of glaciers in polar regions and possibly the start of an Ice Age.

Milutin Milankovitch, a Serbian civil engineer and mathematician, studied these cyclical variations of the Earth in the first half of the 20th century. He brought the cycles together, including the impact of sunspot activity, to show, as in figure 1.1 how the temperature of the Earth has varied over the last million years.

fig 1.1: The combined impact of the Milankovitch Cycles on the temperature of the earth



This scientific research demonstrated that the Earth's temperature has peaked for relatively short periods 13 times over the last million years. Ice Ages of varying severity have intervened. Mankind has experienced a temperate, interglacial period during its main evolutionary period of the last 10,000 years.

During the last decades of the 20th century scientific research in the Antarctic has been able to validate the Milankovitch cycles because the ice at the South Pole is several kilometers thick and has existed for millions of years. Scientists have been able, using drilled cores, initially from Russia's Vostok station, but subsequently confirmed from other stations, to measure the temperature of the Earth over the last 800,000 years. When these measurements are shown graphically they confirm the Milankovitch temperature cycles that are caused by the changing cyclical variations of the earth's orbit around the sun.

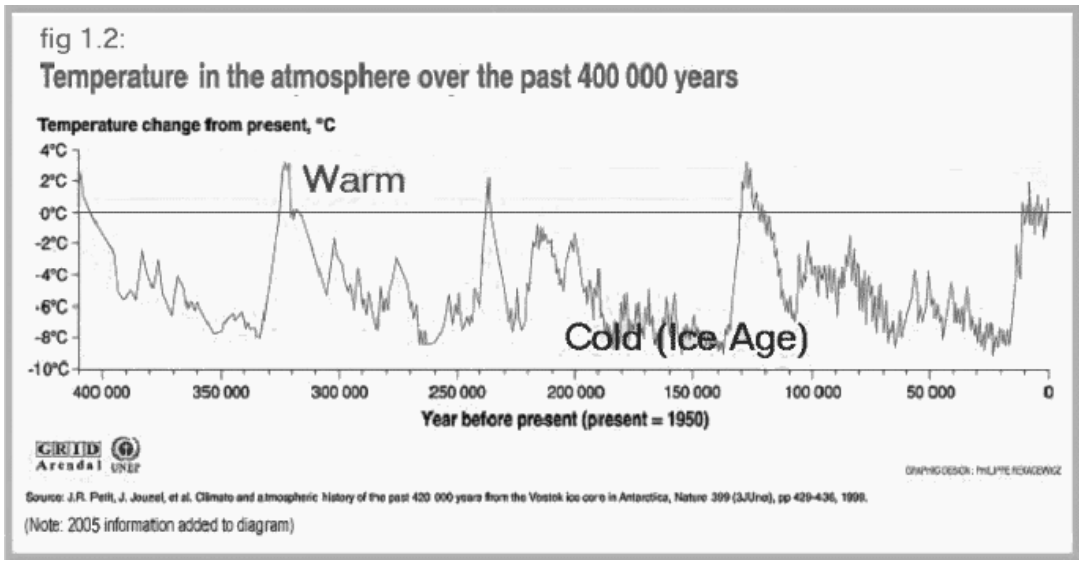
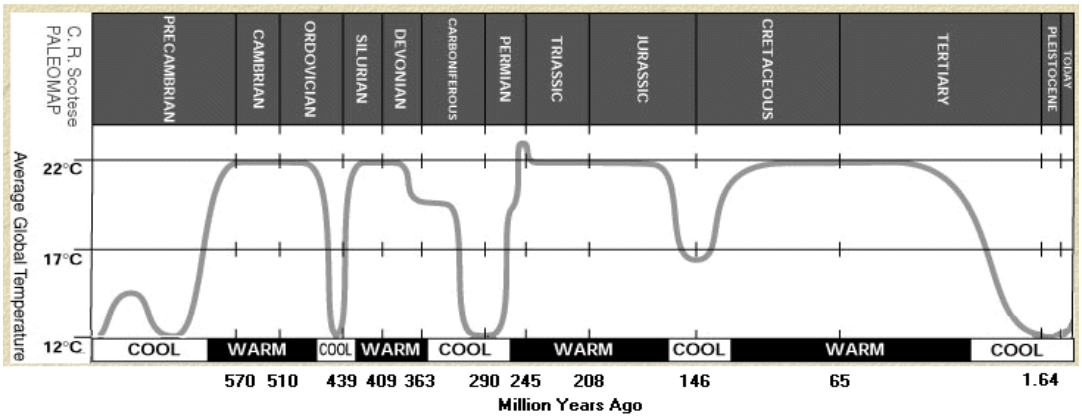


Figure 1.2 shows the Earth's average temperature variation over the last 400,000 years with the cold periods corresponding to recent ice ages. Although the Earth is over 4 billion years old it has mainly evolved over the last 500 million years and scientists have been able to calculate the temperature of the Earth for these geological periods as shown in Figure 1.3.

fig 1.3 Temperature of the earth over geological periods



This shows that on a very long term basis the Earth is currently in a relatively rare, cooler phase. The temperature range for most of the Earth's evolutionary period has been between 17^0C and 22^0C.

Keeping the Earth warm

Although the Earth's position seems to be just right it is in fact supported by a central heating system which adjusts for the Earth being a little too far away from the Sun for comfort. Given its position in the solar system the Earth should actually be frozen over.

The scientists who studied our climate in the 19th century discovered that the energy of incoming Sunlight which is soaked up by the Earth does not equal the infrared energy it creates which should then go back into space. They calculated that the average temperature of the planet should be -15°C with much bigger differences in the temperatures of day and night. They realised that something was keeping the Earth warmer than it ought to be.

The cause of this heating is what we term the 'greenhouse effect' and is caused by something in the Earth's atmosphere. This was explained when John Tyndall, a scientist who was studying the Earth's atmosphere, carried out an experiment that took out all the impurities from air in a large test tube so that only 99% of the atmosphere remained. This was just pure oxygen and nitrogen which he then discovered did not interact at all with infrared energy.

Since the major constituents of the atmosphere made no difference to the temperature of the Earth this had to be caused by something else. John Tyndall then returned a few of the impurities he had removed back to his artificial atmosphere; a little methane, water vapour and carbon dioxide all of which were present in very small amounts in the real atmosphere. Immediately some infrared energy was trapped. The reason for the greenhouse effect had been discovered.

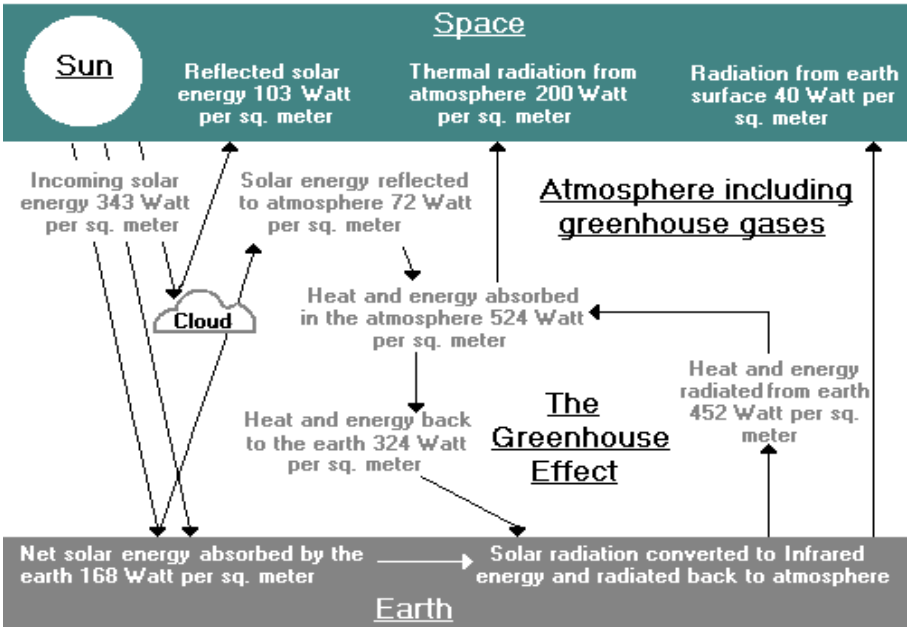
This simple, chemical process in a very small part of our atmosphere is fundamental to life because without intervention by these greenhouse gases the planet would be frozen and lifeless. Every night the warmth brought to the Earth by the Sun would go straight back into space with the Sun rising each day on a world shivering in arctic temperatures.

Although these greenhouse gases represent less than 1% of our atmosphere they are very efficient at trapping infrared radiation and modifying world temperature. The greenhouse gases comprise 95% water vapour, 3.5% carbon dioxide, 1% nitrous oxide, 0.3% methane and small amounts of other gases. When the volume of greenhouse gases is translated into impact on infrared absorption - the greenhouse gas effect - this is complicated because the amount of water vapour in the atmosphere varies considerably across the world, for example it is very low, or not evident in polar regions and the extent of cloud cover also has an impact. On average, however, 45% of the greenhouse gas effect results from water vapour, 25% from carbon dioxide, 20% from clouds and 10% from the other gases, some of which, for example methane, are much more powerful than carbon dioxide.

For the Earth to maintain a constant temperature the energy in the outgoing radiation from the Earth must equal the incoming solar energy. This outgoing radiation comes from three sources- directly reflected solar energy, infrared energy radiated directly from the Earth and infrared energy radiated from the atmosphere.

Figure 1.4 shows how the greenhouse effect provides the secondary warming process that enables the Earth to maintain a higher temperature than would be expected from the position of the Earth in relation to the Sun.

fig 1.4 The Greenhouse Effect

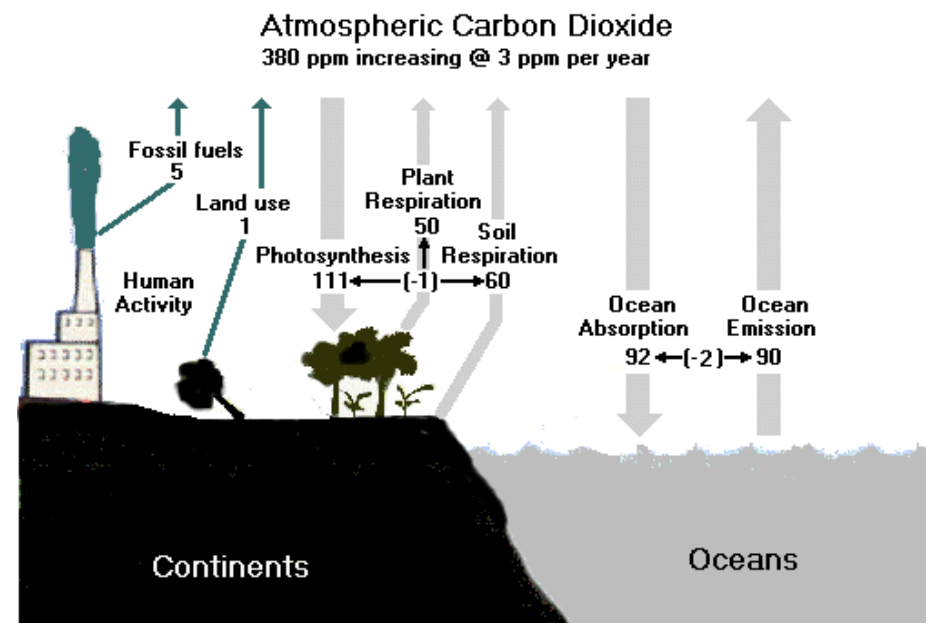


This greenhouse warming process is complex and will vary depending upon climatic conditions across the world. If cloud cover increases more solar energy will be directly reflected back into space. Decreased reflection will also occur if the extent of ice cover reduces. The absorption of energy by the greenhouse gases is related to the volume of greenhouse gases in the atmosphere. If the greenhouse gas concentration increases there is more heat and energy absorbed in the atmosphere some of which will be returned to Earth thereby increasing the temperature of the Earth.

Changes in the temperature of the Earth

In supporting life on Earth the most important greenhouse gas is carbon dioxide and the amount of carbon dioxide in the atmosphere is related to a complex natural process between the atmosphere, land, vegetation and the oceans. This process is known as the carbon cycle as shown in Figure 1.5. This process supports the greenhouse effect.

fig 1.5 The Carbon Cycle



In the natural carbon cycle the oceans absorb more carbon dioxide than they return to the atmosphere. This is also the case with vegetation. However, since the Industrial Revolution mankind has been converting fossil fuels into greenhouse gases and, as population increases, forests have been destroyed in favour of land to produce agricultural crops.

The additional carbon dioxide created by human activity is now in excess of what the Earth can absorb and carbon dioxide in the atmosphere is increasing, rapidly. The concentrations of other greenhouse gases, e.g. methane, nitrous oxide and sulphur dioxide, are also increasing. These increases in greenhouse gases return more energy to the earth, thus causing the temperature of the earth to increase.

If the temperature of the Earth increases due to the level of carbon dioxide in the atmosphere caused by greenhouse gas emissions it will impact on the much larger natural carbon cycle. As temperatures rise the amount of carbon dioxide emitted from warmer soils will increase much more rapidly than can be counteracted by the increased growth of vegetation. Carbon levels in soil across the world are expected to start to decline rapidly from about 2050 as this carbon dioxide is released back to the atmosphere.

Also, carbon storage in vegetation in tropical rain forests will decline as a result of regional warming and drying. This is in addition to the effect of anthropogenic deforestation. From the middle of the 21st century, the land biosphere of the world is expected to switch from being a weak sink for carbon dioxide to an increasingly strong source of carbon dioxide.

The ocean plays an important role in the climate system by regulating the amount of carbon dioxide in the atmosphere. About 40% of the carbon dioxide currently produced by anthropogenic greenhouse gas emissions is absorbed by the oceans. Carbon dioxide from the atmosphere dissolves in surface waters and, on entering the oceans, undergoes rapid chemical reaction with the water with only a small fraction remaining as carbon dioxide to take part in subsequent ocean–atmosphere interaction. This dissolved carbon enters the deep waters of the ocean and is removed from interaction with the atmosphere for hundreds of years. As more carbon dioxide can dissolve in cold water than in warm, the colder, denser waters towards polar regions move larger quantities of carbon from the surface to deep waters.

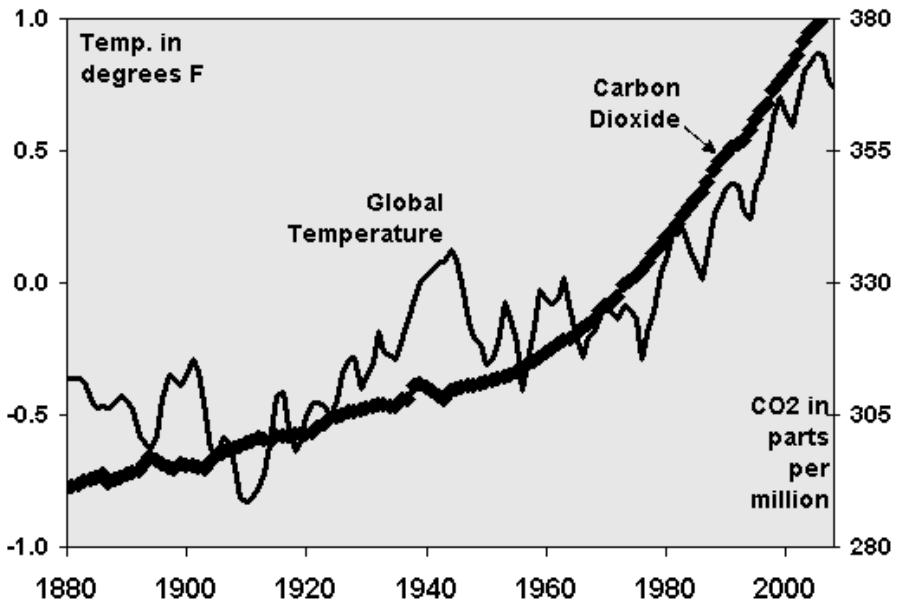
Through normal ocean circulation patterns these deep cold waters eventually return to the surface, increase in temperature and release carbon dioxide which returns to the atmosphere. In general the surface of oceans near the tropics releases carbon dioxide to the atmosphere whilst the surface of the oceans toward the Polar Regions absorbs carbon dioxide. As the Earth's temperature increases net carbon dioxide emissions from the oceans will almost certainly increase.

Increases in the Earth's temperature due to increased greenhouse gas emissions are expected to cause changes in the natural carbon cycle to the extent that the carbon dioxide concentration in the atmosphere may increase by a further 60% by 2050 which will progressively accentuate global warming throughout the 21st century.

It is convenient to measure greenhouse gas concentrations in the atmosphere in terms of parts per million (ppm) and the current rate of increase in the concentration is approximately 2-3ppm each year.. The concentration of carbon dioxide in the atmosphere for about 10,000 years before the start of the industrial revolution was about 280ppm but this has risen consistently since 1960 to over 380ppm today. This is the highest level for over 1 million years. In addition concentrations of methane have doubled and nitrous oxide has increased by 20%.

Figure 1.6 shows that in recent years the temperature of the Earth has increased in line with the amount of carbon dioxide in the atmo

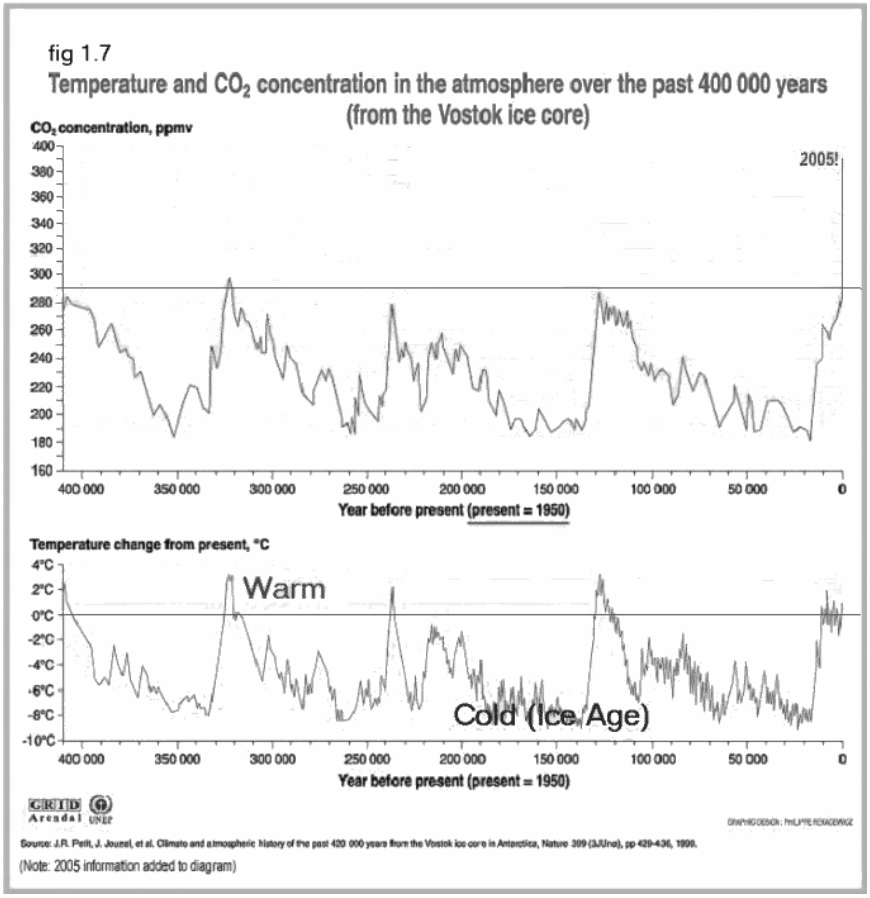
fig 1.6 Global Temperature and Carbon Dioxide



Over 90% of climate scientists in the world consider that the human activity that is causing emission of greenhouse gases has caused additional infrared absorption and has caused the recent increase in the average temperature of the world atmosphere. This is known as the 'Consensus' view. This view is supported by the information obtained from the ice cores which were drilled at Russia's Vostok station in the Antarctic where scientists were able to measure not only the temperature of the atmosphere but also, from air bubbles in the ice, the concentration of carbon dioxide going back over 400,000 years.

We already know from the Milankovitch cycles that the temperature of the Earth is caused by the cyclical changes in the Earth's orbit over time. As shown in Figure 1.7 it was also possible from the ice core measurements to illustrate and compare the concentration of carbon dioxide in the atmosphere in parts per million to the earth's average temperature. Figure 1.7 demonstrates that there appears to be a close relationship between temperature and the concentration of carbon dioxide in the atmosphere. However, scientists who studied the Milankovitch cycles carefully noted that the change in the concentration of carbon dioxide in the atmosphere lags slightly behind the temperature change.

They concluded that the temperature change at end of an Ice Age, or end of a warm period, is caused, initially, by changes in the Earth's orbit that increase, or decrease, the amount of solar energy received by the Earth. This temperature change then causes change in the climate, the greenhouse effect and the level of carbon dioxide in the atmosphere.

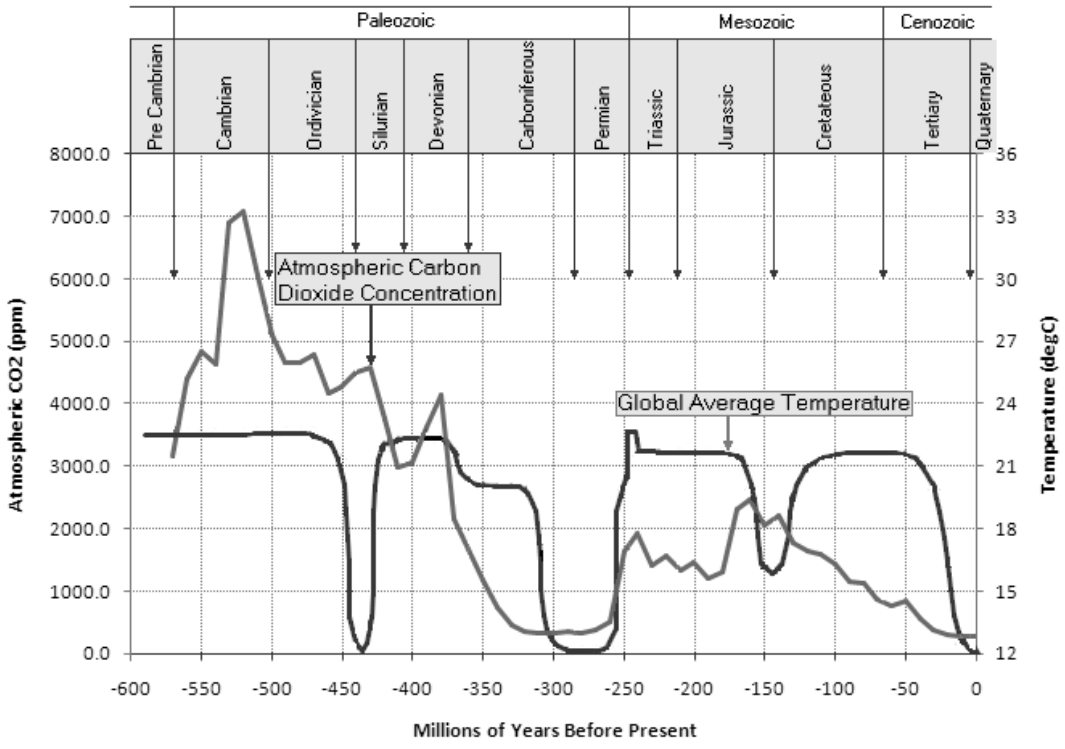


These are the primary reasons why the Earth's temperature, and in particular the temperature of the oceans, changes. The amount of carbon dioxide held in the oceans changes with ocean temperature. The additional carbon dioxide released, or absorbed, then enhances the greenhouse gas effect which further changes global temperatures.

However, a significant number of scientists consider that factors other than the orbit of the Earth and the concentration of greenhouse gases in the atmosphere have a major impact on the current temperature of the Earth. Their views are known as the 'sceptics' view.

Recent forecasts of the extent of global warming seem to have been based on extrapolating the relationship between global temperature changes for the last 200 years and greenhouse gas concentration. If one goes back in time, however, this relationship does not appear to exist as shown by Figure 1.8

fig 1.8 Global Average Temperature and Atmospheric Carbon Dioxide Concentration over Geological Periods



Analysis of temperature oscillation after C.R.Scotese 2002. Analysis of atmospheric carbon dioxide after R.A.Bremner 2001

Figure 1.8 shows quite clearly that the concentration of carbon dioxide in the atmosphere has varied extensively over the last 500 million years but the average temperature of the Earth appears to have been constant for millions of years at about 22^0C. In more recent times the concentration of carbon dioxide has varied between 280 and 400 ppm whilst the average temperature of the Earth has remained constant at around 14^0C. This seems to confirm the 'sceptics' view that carbon dioxide concentration is not directly related to the temperature of the Earth.

Therefore, whilst the orbit of the Earth, the greenhouse effect and the concentration of carbon dioxide in the Earth's atmosphere all clearly have important impacts on the temperature of the Earth there must be other phenomena at work. Some of these are advanced by the climate change 'sceptics'.

Water vapour, which constitutes up to 95% of green house gases, is not affected by human activity. Temperature determines the level of water vapour in the atmosphere, which creates clouds and returns to the Earth as precipitation. Some scientists consider that increased levels of carbon dioxide increase the amount of water vapour which enhances the greenhouse effect. It is recognised, however, that the science underpinning water vapour and climate modelling is still under-developed. The amount of water vapour in the atmosphere changes every day and, unlike the other greenhouse gases, is very transient.

Natural phenomena such as earthquakes have a major, but short term impact on the temperature of the Earth. Large, explosive volcanic eruptions inject water vapour, carbon dioxide, sulphur dioxide, hydrogen chloride, hydrogen fluoride and ash into the stratosphere to heights of 16–32 kilometres above the Earth's surface. The most significant impacts from these injections come from the conversion of sulphur dioxide to sulphuric acid, which condenses rapidly in the stratosphere to form fine sulphate aerosols. The aerosols increase the reflection of radiation from the Sun back into space and thus cool the Earth's lower atmosphere.

However, these aerosols also absorb heat radiated up from the Earth, thereby warming the stratosphere. Several eruptions during the past century have caused a decline in the average temperature at the Earth's surface by up to half a degree for periods of one to three years. The sulphate aerosols also promote complex chemical reactions which in part damage the ozone layer and create acid rain. Volcanoes do not, however, have any long term impact on global temperature.

The El Niño-Southern Oscillation is an ocean-atmosphere phenomenon, which impacts on the whole world, and with the associated La Niña create important temperature fluctuations in the surface waters of the tropical Eastern Pacific Ocean. El Niño, which is an ocean warming event is usually noticed around Christmas time in the Pacific Ocean off the west coast of South America and is followed by La Niña which is an ocean cooling event. These phenomena occur at irregular intervals every 2 – 7 years and can cause short term changes in global temperatures. The slow down in temperature increase at the beginning of the 21st century is said to be due to the cooling impact of La Niña compared to the warming impact of El Niño in 1998. This global phenomenon does not change the general trend of global warming.

Beyond these natural phenomena which cause short term changes in climatic conditions there is, however, one natural phenomenon which has been shown to exert a significant impact on world temperature. It is seen by some of the ‘sceptics’ as being more important than the greenhouse effect and the emission of greenhouse gases through human activity.

Sunspots are regions of the Sun’s surface that are marked by lower than average temperature. They have intense magnetic activity, inhibit convection and form areas of reduced temperature on the Sun’s surface. Since sunspots are darker than the surrounding areas on the Sun it might be expected that more sunspots would lead to less solar radiation. However, the area surrounding sunspots is hotter than the average, and so is brighter. Overall, more sunspots increase the Sun's brightness, the level of radiation and, therefore, the temperature of the Earth.

Sunspot cycles occur on an irregular cycle on average every 11 years. In recent times cycles have been as short as nine years and as long as 14 years. At the beginning of the 21st century, the Sun is at a high level of sunspot activity. Scientists have measured sunspot activity for many years and the relationship of sunspot activity to the Earth's temperature is shown in Figure 1.9

fig 1.9 Sunspot activity and the temperature of the earth

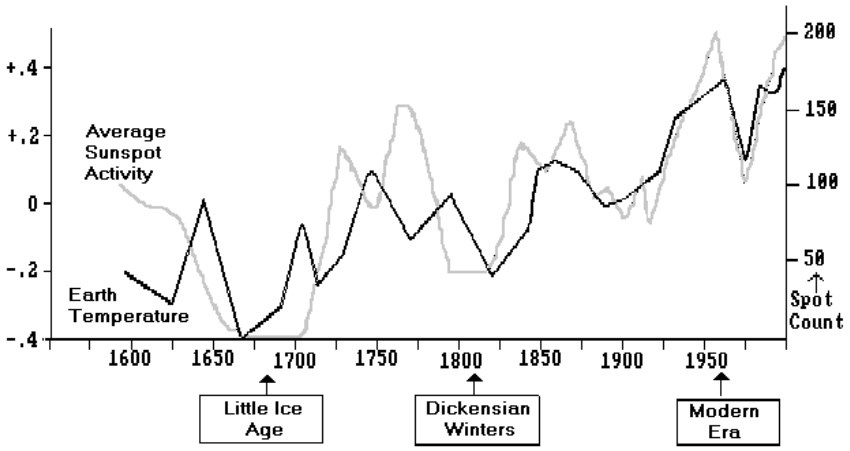
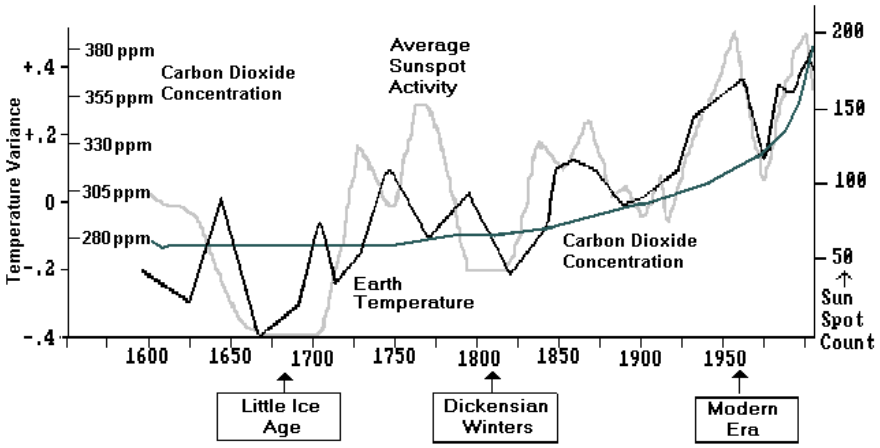


Figure 1.9 shows that there has been a close correlation between the temperature of the Earth and sunspot activity which has driven changes in the Earth temperature in recent centuries. However, when the relationship between Earth temperature, carbon dioxide concentration and sunspot activity is combined, the strength of increasing carbon dioxide concentration is seen to enhance the increase in the Earth's temperature as shown in Figure 1.10

fig 1.10 Temperature of the earth, sunsport activity and carbon dioxide concentration



In 2007, the sunspot cycle reached its minimum and with a very low level of activity in 2008. Some of those who predict sunspot activity are forecasting that the start of the next cycle will be delayed by 6 to 12 months with this cycle peaking in 2012. Some say that it may be a strong sunspot cycle which may accentuate global warming.

The Earth's temperature was lower than previous years in 2006 and 2007 probably due to lower sunspot activity and the cooling effect of the La Niña in these years. With the predicted high level of sunspot activity from 2010 and the continued increase in greenhouse gas emissions it must be expected that the Earth's temperature will regain its upward trend. Some scientists, however, are forecasting a sharp reversal in sun spot activity for the next 25 years which may, or may not, reduce temperature.

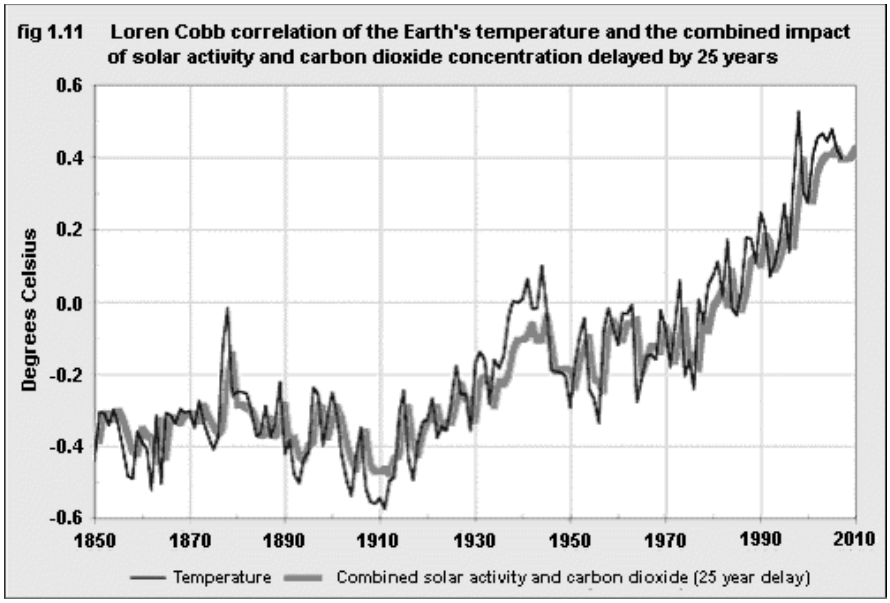
The Intergovernmental Panel on Climate Change (IPCC) which represents the 'consensus' view dismissed the impact of sunspot activity and other phenomena in the summary of their 4th Assessment Report, which was published in November 2007. The summary report stated that *"During the past 50 years, the sum of solar and volcanic forcings would likely have produced cooling. Observed patterns of warming and their changes are simulated only by models that include anthropogenic (human activity) forcings. Difficulties remain in simulating and attributing observed temperature changes at smaller than continental scales".*

The scientific evidence available clearly shows that sunspot activity has been the natural phenomenon that determines the temperature of the Earth on a short term basis. Those who have correlated sunspot activity and the Earth's temperature have shown that there is a close short term relationship. This is illustrated in figure 1.9 above.

The scientists who support the IPCC and the 'consensus' view will be aware of the importance of sunspot activity, but for reasons that are not clear have decided not to bring sunspot activity into their conclusions and forecasts for global temperature.

Mankind has no influence on sunspot activity but can influence the extent that greenhouse gas emissions are allowed to drive economic activity and growth. Since the IPCC is an Intergovernmental Panel it is understandable that it is concentrating on those issues which mankind controls. However, if the IPCC had recognised the impact of sunspot activity in their conclusions it might have prevented the climate change 'sceptics' from criticising their approach and their conclusions.

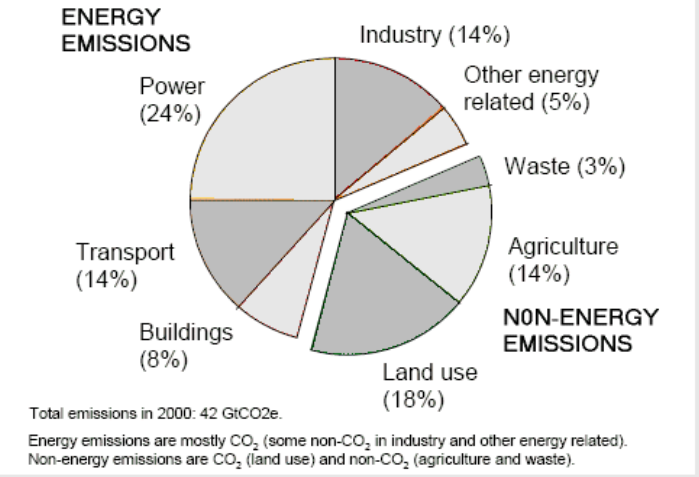
One scientist, Loren Cobb, researched the possibility of comparing the increase in the Earth's temperature with the combined impact of the measurements for solar activity and the concentration of carbon dioxide. In his research he noted that there appeared to be a time lag between the time that the carbon dioxide went into the atmosphere and temperature change. In his view the time lag is 25 years. In his published paper 'The Causes of Global Warming – A graphical approach' he demonstrates that there is a close correlation between the average temperature of the Earth and the combined impact of solar activity and increased carbon dioxide concentration where the latter is delayed by 25 years. The correlation is shown in Figure 1.11. Time will tell whether this apparent relationship is valid which may be demonstrated if sunspot activity declines significantly in the next 25 years.



The source of greenhouse gases

The source of greenhouse gases is well researched and documented. One authoritative source is the UK Government's Stern Review on the impact of climate change which was published in 2005. This review details the worldwide sources of greenhouse gases which are illustrated in Figure 1.12.

Fig 1.12 **Greenhouse-gas emissions in 2000, by source**

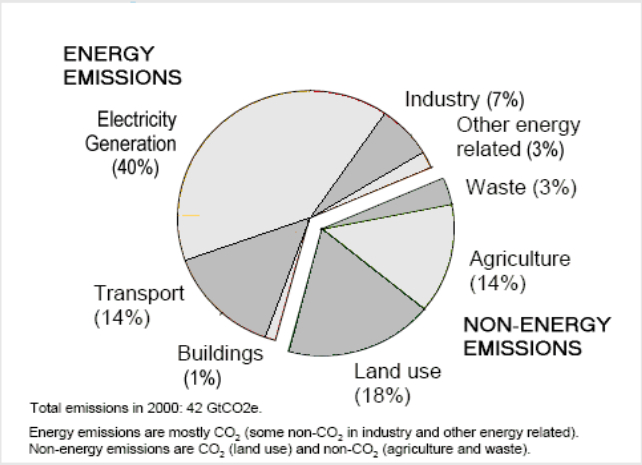


Source: Prepared by Stern Review, from data drawn from World Resources Institute Climate Analysis Indicators Tool (CAIT) on-line database version 3.0.

This chart however, can be said to be slightly misleading since 90% of the emissions that are shown as coming from buildings, worldwide, actually originate from electricity generation. The same is true of industry and other energy use sectors where at least 50% of the emissions originate from electricity generation.

It is possible, therefore, to re-compile the diagram to show the origination of greenhouse gases as related to electricity generation. Figure 1.13 now shows that 40% of greenhouse gases originate from electricity generation, as against the 24% shown as originating from power in figure 1.12. It is useful, however, to use both charts when understanding where greenhouse gases originate.

Fig 1.13 **Greenhouse-gas emissions in 2000 as related to electricity generation**



Source: Modified from the diagram from the Stern Review, from data drawn from World Resources Institute Climate Analysis Indicators Tool (CAIT) on-line database version 3.0.

In the transport segment motor vehicle technology is beginning to change rapidly with movement away from the internal combustion engine. One change, which is developing, rapidly, is the manufacture of electric vehicles where batteries are being developed that are lighter and far more efficient. Batteries, however, have to be charged using electricity. This further highlights the importance of electricity generation as a source of greenhouse gases. The percentage of greenhouse gases originating from electricity generation could rise to over 45%.

The forecast for global warming

The world as we know it today has a climate that has been unusually steady. Mankind can be said to be particularly lucky to have been able to evolve in an interglacial period as shown by the Milankovitch cycles. Over millions of years the planet has seen changes in temperature and climate far larger than those recorded in the last 400,000 years. In some geological periods mankind would have been unable to exist. For example in the distant past CO_2 levels in the atmosphere were ten times than today and Antarctica was a tropical paradise. There were other times when CO_2 levels were much lower and the equator had winter conditions although, as shown previously, there is not a direct correlation between carbon dioxide concentration and global temperature.

Over these geological periods the vegetation of the Earth has been very extensive with huge forests covering much of the Earth. Forests constantly change as vegetation decays and during the Ice Ages these forests declined as the majority of the Earth was covered in ice. With time the shape of continents and the Earth's surface changed with layers of decayed vegetation forming the fossil fuel deposits of coal, oil and gas which provides mankind with its most important source of energy today. In a few hundred years mankind will have used a large proportion of the fossil fuels that were created over millions of years.

For the last 10,000 years, which is the time that human civilization has existed, the Earth's temperature has varied to only a limited extent. These variations within centuries have been mainly caused by sunspot activity but supported by carbon dioxide concentration, e.g. these combined to cause the average 0.4^{0}C drop in temperature in the 17^{th} century, which caused the River Thames in the UK to freeze over every winter.

Whilst sunspot activity supported by carbon dioxide concentration has continued to combine in recent millennia to determine global temperatures the extent that greenhouse gases are increasing due to human activity has clearly become an important factor in current global warming, as set out by the IPCC. As stated earlier, however, the IPCC have decided not to bring sunspot activity into their calculations and forecasts for the Earth's temperature.

People today have become used to a world where the climate and temperatures change through the seasons and where the extent of climate change can be anticipated and enjoyed. Humans can also live in almost every part of the world except the polar regions. The key issue for the 21^{st} century is whether the rise in global temperatures, as driven by human activity, will impact in a major way on the delicate balance of the carbon cycle and the world eco-systems, and thus on living conditions throughout the world.

The concentration of carbon dioxide in the atmosphere is above 380ppm in 2008 and this is currently increasing at 2-3 ppm per year. Governments and their citizens are increasingly concerned about the potential impact of global climate change and are taking action to reduce greenhouse gas emissions through the type of technology employed and the reduction of waste and inefficiency. Change, however, will take time and world economic activity is increasing together with world population. This means that greenhouse gas emissions will continue to increase for at least next decade before they can start to reduce on an annual basis, worldwide. The scale of reduction will vary between countries.

Scientific data shows that world temperature has increased by 0.6^0C over the last 100 years and sea levels have risen by 200mm. The International Panel on Climate Change is forecasting a continued rise in temperature of 0.2^0C for each of the decades immediately ahead. This may increase as temperature increases in the oceans, which are delayed, become a contributory factor.

On an overall basis it is can be expected that significant greenhouse gas emissions will continue to take place during the first half of the 21st century and, if the 'consensus' view of the IPCC is correct, the minimum temperature rise by 2100 will be at least 2.5^0C with the probability of a higher rise. The extent of any rise of 2.5^0C will depend on the extent that the nations of the world unite to provide global solutions to global warming cause by increased use of fossil fuels, increases in world population and continued economic development, worldwide.

The impact of global warming

If the 'consensus' view is correct a rise in temperature of least 2.5^0C is inevitable and this will create major changes in living conditions across the world that will have to be accommodated by governments and their citizens. The higher the average temperature rises the greater will be the impact on nations worldwide.

Antarctica is a continent covered in ice and surrounded by oceans. The ice on its land is several kilometres thick in places and is millions of years old. It is not susceptible to extensive melting except for the western ice shelf. The climate here is warming much less than in the Arctic where the North Pole is located on sea ice. Greenland, however, is covered in a large ice cap which - like Antarctica, is four kilometres thick in parts. The sea ice is melting in the Arctic to a greater extent each summer and measurement shows that it is likely that the Arctic will be completely free of sea ice each summer before 2020. Whilst this will open up new, and valuable, shipping lanes between Europe and countries in Asia and Western America the ecosystem of the Arctic will change beyond recognition.

Away from the Polar Regions higher temperatures will alter weather patterns. There will be less snowfall and more variable and intense rainfall patterns. Glaciers will melt. Some tropical regions in the world could become 30% wetter whilst more temperate areas could become 30% drier. Intense rainstorms will increase local flooding but water could become very scarce in some parts of the world. The impact of temperature increase on monsoons is unclear although some scientists believe they will get drier. Summer heat waves will become increasingly common with many regions likely to suffer the consequences of dry, hot summer periods with increasing incidence of fire. The main impact of such climate change is that yields from agriculture will reduce in many regions although in some areas yields will increase. Crop reduction will be particularly evident in parts of Africa and Asia whose populations only emit a tiny amount of greenhouse gases. It will become evident that those who are least responsible for greenhouse gas emission will suffer the most.

Inevitably major changes in climate change and food availability will stimulate people to live in different parts of the world, which will cause tension between nations as migration, legal - or illegal, increases. Moving location will not be difficult for those who have the necessary financial resources but this will not be an easy option for the billions of poorer people across the world.

The melting of land ice in the Arctic, and to some extent in the Antarctic, plus melting from glaciers has already had some impact on sea levels, which have increased by 200mm over the last century and will continue to increase throughout the 21st century and beyond. This will be caused by glacial ice, particularly from the Greenland and Antarctica ice sheets, melting and entering the oceans. The extent of the increase in sea levels is difficult to predict but even a rise of 300mm will impact when high tides and extreme storms threaten existing sea defences. Climate scientists forecast that if the temperature increases by 2.5^{0}C sea levels will rise by about one metre by the end of the 21st century and by up to 10 metres through the next millennium as glacial ice continues to melt with higher temperatures.

This means that some low lying islands will no longer exist and the flood defences of many cities in the world will have to be increased substantially, or introduced for the first time. 20% of the major cities in the world are located close to the sea and some may even be abandoned in the centuries ahead. There are also countries, such as Bangladesh, which could become almost completely submerged.

This will further intensify immigration across the world and cause disruption to nations and communities. The impact will be so great for some nations that it is difficult to forecast how the disruption will be resolved. It will be a major issue for the United Nations.

Turning to the natural environment, the oceans absorb carbon dioxide as part of the carbon cycle and the amount absorbed has increased in recent years and may continue to increase. This has caused the acidity levels of the oceans to increase. Whilst the oceans have a natural ability to compensate for such increases over time the rate of increase has been so rapid that the new level of acidity is bleaching coral reefs and is threatening the delicate balance of various forms of sea life, e.g. it is working to prevent the formation of shells for various types of mollusc. On a wider basis, however, those who are concerned with natural life believe that 30% of existing species may become extinct.

Although the natural and anthropogenic phenomena that control the temperature of the Earth and its climate are complex the scientific evidence indicates that there is a strong probability that the average temperature of the Earth will increase significantly throughout the 21st century. Due to complexity, climate scientists are unable to predict the temperature levels that will be reached. Higher temperatures, however, will cause extensive change in climate and ecological conditions and mankind will have to learn how to live with the impact of these changes.

If mankind had failed to identify the value of fossil fuels in providing the energy that has driven economic development for the last 200 years the comfortable temperature of the Earth and its climate would probably have continued for several millennia into the future with mild fluctuation due to solar activity. But as higher temperatures now make their impact, mankind will have to accelerate action to reduce and ultimately near eliminate greenhouse gas emissions.

Scientific data appears to show that natural phenomena have driven temperature change which then increases/ decreases carbon dioxide concentrations which contributes to further temperature change. The impact of un-natural anthropogenic greenhouse gas increases in the atmosphere on the Earth's temperature is not yet fully understood and the 'sceptics' view may demonstrate over time that the impact of increased greenhouse gas emissions on the Earth's temperature is far less than that projected by the IPCC.

If this is the case it will be argued that the 'green' taxes that are, and will be, raised by Governments to reduce greenhouse gas emissions in line with the 'consensus' view were un-necessary and caused by the natural desire of politicians to raise income from taxation. Citizens will point out that the politicians of the world should have concentrated more on addressing other issues such as population growth, food supply, utility costs, flood defences or depletion of world resources.

Alternatively it can be argued that carbon dioxide concentration has already increased to unprecedented levels in the atmosphere for the last million years and mankind must agree, collectively, as a matter of urgency how to stabilise and reduce the level. It is probable that due to the length of time that carbon dioxide remains in the atmosphere it may take a millennium for mankind to stabilise the Earth's climate conditions and restore the comfortable environment that has existed for the last 10,000 years.

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The intention of this article is to advance knowledge and understanding of some issues associated with climate change. The views expressed are those of the author and do not, necessarily, represent the views of the Comino Foundation.