# ON CLIMATE CHANGE...


## FACTS, MYTHS AND SERIOUS QUESTIONS

PIER VELLINGA

Vrije Universiteit Amsterdam

PIER VELLINGA

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*Facts, myths*

*and unsolved questions*

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## *Table of Contents*

# *Introduction*

Why are some people so deeply concerned about climate change, while others seem undaunted? Can we even speak of climate change, when Europe has seen some of its coldest winters in recent history these past few years? And if climate change is indeed a fact, how can we be sure that we humans are responsible? The overwhelming majority of experts agree that it is indeed getting warmer, but is that such a bad thing? Does that not have benefits as well?

Climate change: separating fact from fiction can be a challenging task. This book examines the questions that most people deal with, but not always dare to ask. Without shying away from the uncertainties involved, the book aims to provide the reader with a clear insight into what we do and do not know about human influence on climate, and how we can deal with this. While the future remains uncertain, more knowledge can help us stand stronger in the face of climate change.

# 1

## *Climate change – who should we believe?*

Researchers who warn us about the consequences of climate change, such as melting icecaps, get plenty of attention in the media. Because the media are fond of drama. At the same time there are climate sceptics, politicians and others, who deny the existence of climate change or try to downplay its importance. They show charts that demonstrate that the number of polar bears is actually growing, or that temperatures have not increased over the past ten years. And where they do admit to changed temperatures, they blame it on changes in solar activity. These two camps, with their opposing views, are engaged in a fierce discussion that has been running for years. But what is the reality? Who should we believe, and can we actually support either one of these viewpoints?

**Additional greenhouse gases, where do they come from and what is their influence?**

Measurements of the air surrounding the Earth show that the amount of greenhouse gases[1] in the atmosphere has increased significantly over the last decades. There are multiple causes, including the use of coal, oil and gas, but also deforestation and developments in agricultural practices and the food supply chain. There is much ado about the impact these gases might have on global climate.

This debate is not directly focused on the changes in the atmosphere. The measurements leave little room for uncertainty on that front. Neither are the origins of these additional greenhouse gases the topic of discussion. The carbon atoms in $CO_2$, carbon dioxide, that originate from fossil fuels (that were formed millions of years ago) look slightly different in isotope analysis than the carbon atoms in $CO_2$ that was formed more recently. Measurements demonstrate that the percentage of atmospheric carbon that comes from fossil fuels is rising. The real point of discussion is to what degree these additional greenhouse gases influence global climate, and how this effect compares to natural processes that also influence our climate.

In this discussion, $CO_2$ emissions from fossil fuels get most of the attention. This is no surprise, as they form the largest contribution to the increase of greenhouse gases in the atmosphere. However, another greenhouse gas that is increasingly present in the atmosphere is methane gas ($CH_4$). Methane gas is emitted from wet rice paddies, from ruminant cattle and from waste. The concentration of nitrous oxide ($N_2O$), another gas that contributes to the greenhouse effect, has also risen sharply. One source of nitrous oxide emissions is the use of artificial fertilizers. Laboratory tests show that the greenhouse effect generated by the molecules of each of these gases differs. In order to make a comparison, their effect is usually expressed in terms of '$CO_2$ equivalent'. The amount of global greenhouse gas emissions and their development over the last 40 years are displayed in figure 1.

## WORLDWIDE EMISSIONS OF GREENHOUSE GASES

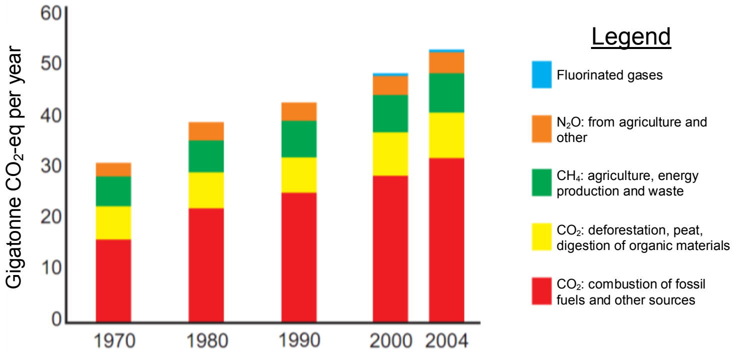



*Figure 1. Development of the amount of greenhouse gases that are released globally, expressed in $CO_2$ equivalents. [Source: IPCC (2007)[2]]*

The abovementioned gases are named 'greenhouse gases' because the effect they have on radiation of different wavelengths causes heat to become trapped in the atmosphere. Experiments have shown that they let energy in the form of visible light through freely (i.e. radiation with a short wavelength, like sunlight), while they have an inhibitory effect on heat radiation originating from a hot object (infrared radiation, which has a longer wavelength). When a hot object emits radiation, the amount of that radiation which gets blocked increases with the amount of greenhouse gases present between the object and its receiver. Based on these laboratory results, one would expect that the earth will get warmer when the concentration of such gases increases, because the greenhouse gases in the atmosphere make it more difficult for the Earth to lose the heat it receives from the sun.

The big question, and this is what the debate focuses on, is whether these greenhouse gases have the same effect on the earth as they do in a laboratory environment. The answer seems to be a simple ‘yes, why not?’, but there are many more processes at work that influence the earth’s climate, such as variations in solar activity, volcanic activity, fluctuations in atmospheric water vapour concentrations, shifting ocean currents and air pollution. Moreover, these processes interact with each other and with the effects of additional greenhouse gases.[3] As a result, the answer to this question cannot be an unequivocal yes.

Furthermore, it is impossible to stage experiments that are on a scale with the earth. An exact prediction of the degree to which the additional greenhouse gases will influence the earth’s temperature is therefore difficult to make.[4] Another important question we need to ask ourselves is how much of a difference it would make if the earth were to warm up slightly. After all, there have been warmer and colder periods throughout earth’s geological history.

Scientists have diligently researched these issues over the last 30 years, and the results from geological research, model simulations and direct measurements all support the hypothesis that $CO_2$ and other greenhouse gases have an important impact on our climate on a global level. How large that influence is exactly and what implications this will have will always remain somewhat uncertain, because human influence on climate and natural climate fluctuations are intertwined.

In order to make predictions about the future we have to make some assumptions. But these assumptions may be subject to bias. As a result, many people wonder whether climate scientists are overstating the problem.

Since about 1980 research on the influence of greenhouse gases on global climate is being done on a large scale. There were some early indications of this influence, but at the time only a few scientists were active in this field. In 1990 the first report of the United Nations' climate panel, the IPCC[5], appeared. Ever since, this panel has released a new report roughly every five years. These reports show with increasing certainty that we are dealing with a very major, but at the same time very complicated problem. The IPCC report of 2007 left little room for doubt about the reality of human impact on our climate and the possible consequences of this impact. In this report, it is noted that in a worst case scenario the average temperature of the earth could rise up to 6 degrees Celsius by the year 2100. If the odds are with us, the increase could be limited to 1 to 2 degrees.

When the report first appeared, the panel was heavily criticised for the certitude with which this conclusion was presented. When, at the start of 2010, several errors were found in the report, the whole report became subject to debate. The question 'how significant is the influence of additional greenhouse gases?' was repeated again, along with 'is it really worth pumping billions into developing a climate neutral energy supply in an effort to limit climate change?

Indeed, if the rise in surface temperature would be limited to one degree, nature and mankind would be able to adapt reasonably well. If nobody told us about it, we probably would not even notice the difference. But if temperatures rise by 2 or 3 degrees, or even more, in the next hundred years, then we will most likely be facing a huge international problem. We would be dealing with an accelerating global rise in sea levels, combined with an increasing number of disasters, such as widespread floods, water shortages and the spreading of diseases among people and plants into areas where they previously did not exist.

**What is climate?**

In everyday language, ‘climate’ is something we expect, and ‘the weather’ is what we get. But what exactly do we mean when we talk about climate?

When we discuss climate, we are concerned with the average amount of precipitation, temperature and wind that you would expect, including all possible variations and extremes. Meteorologists usually determine the mean and the variation using measurements over a period of thirty years; this fairly long period gives a better indication of trends and natural variations than much shorter periods would. To determine the frequency or intensity of extreme weather events, even longer time periods are considered. Decisions on the required strength of dikes in the Netherlands, for example, are based on measurements regarding the behaviour of the North Sea and the Dutch rivers dating back over 150 years.

The climate on earth has not always been the same. In geological history, we see warmer and colder periods. The last great ice age, for example, ended roughly 20,000 years ago. The next one will probably start some 10,000 to 20,000 years from now. Human behaviour so far has not influenced these very long term changes. Within the different periods our climate is relatively stable, and variations are relatively small. Since about 10,000 years, we have been at the peak of a naturally warm period.

**The sun, volcanoes and El Niño**

As mentioned before, some climate sceptics claim that the (in their eyes uncertain) global warming is due to changes in solar activity. Indeed, the intensity of the sun varies according to shorter and longer cycles, but the influence of this variation on the average temperature is not entirely clear. Furthermore, it is a cyclical influence, alternating between warmer and colder periods. The most well-known cycle is the solar cycle[6], with a period of roughly 11 years (see figure 2). But there are longer cycles too, one lasting about 90 years and one that lasts between 200 to 250 years (see figure 3). The impact of these longer cycles can be seen in the history of Europe; for example, the Little Ice Age took place between 1600 and 1800. Before that, starting approximately in the year 900, there was a warmer period, when wine was produced in England and the Vikings started inhabiting the southern tip of Greenland (950 AD). In those years there was little ice around the shores (hence the name 'green' land) and it was warm enough to grow food there.

## 11-YEAR SOLAR CYCLE

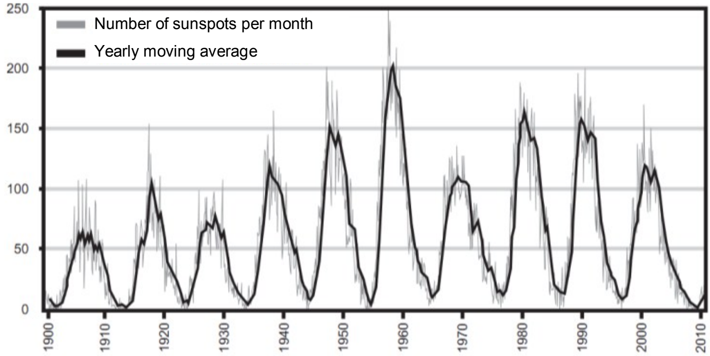



*Figure 2. The intensity of the sun varies with a periodicity of roughly eleven years. This influences the composition of the atmosphere and the amount of heat that reaches the earth; in periods with many sunspots, more heat reaches the earth. [Source: SIDC[7]]*

## SOLAR ACTIVITY OVER THE LAST 2,000 YEARS

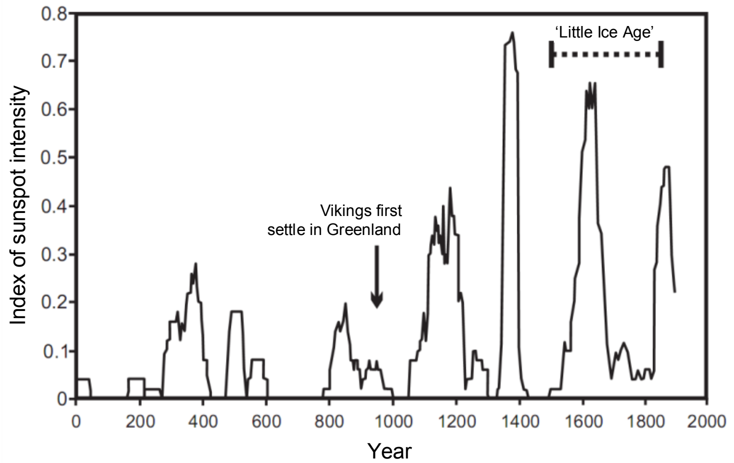



*Figure 3. There are also variations in the amount of solar activity with periods of 90 and 250 years [Source: Vaquero, Advances in Space Research, 2007[8]]. It remains difficult to link variations in temperature to variations in sunspot intensity. Paintings that should reflect the Little Ice Age, for example one by Avercamp (1608) (see figure 14 in chapter 3), date from a period with a high sunspot intensity.*

Volcanic eruptions also have a measurable influence on the average weather conditions. The substances that are emitted into the atmosphere, especially ashes and sulphide compounds, temporarily block part of the incoming radiation from the sun. After large eruptions, global temperatures tend to drop for some years, until the dust has cleared from the sky.

Besides this, more or less random changes in ocean currents and airstreams in the higher atmosphere (jet streams) can cause considerable variations in the earth’s average temperature, in the range of half a degree Celsius. Warm years are followed by cold ones, the cause of which mainly lies in the oceans. Oceans are enormous heat buffers, and through the variation of wind patterns and the resulting periodical fluctuations in the exchange of warmer surface water with deeper, cooler water, they absorb more heat in some years than in others. The El Niño phenomenon is a (well known) expression of this.

El Niño (Spanish for ‘the child’) refers to the Christ child. It is so named because it usually manifests itself around the end of the year. The El Niño phenomenon can be described as follows: in the Pacific Ocean, around the equator, in the area between Peru and Indonesia, the surface water warms up due to the sun. Because of the prevailing wind this water is blown westwards, which causes a layer of warm water to build up against the coasts of Indonesia and South-East Asia. This warm layer slowly expands in the direction of South America, until it reaches the shores of Peru. Once every two to seven years, this upper layer of warm water becomes unstable and mixes with the deeper, cooler ocean water. In the period right before this change (El Niño), the ocean water and the air above it are relatively warm.[9]

The somewhat irregular El Niño cycle influences the average global temperature and causes regional droughts and rainfall. The exceptionally hot year of 1998 occurred in the middle of a very strong El Niño, as did the, albeit less hot, year 2005. The heavy rainfall which caused severe floods in

Pakistan (see figure 4) and other places around the world in 2010 was also preceded by an El Niño. In the first half of 2010, the temperature at the surface of the Indian Ocean was at a record high. This caused more water to evaporate, which in turn led to heavier monsoon rains.

**FLOODS IN PAKISTAN**


*Figure 4. Floods in Pakistan as a result of excessive rainfall, July-September 2010. [Image: BBC News 2010[10]]*

The counterpart of El Niño is La Niña. La Niña is characterised by cooler water at the Peruvian coast and warmer water at the Indonesian and Australian coasts. In the latter area, this gives rise to more rainfall and an increased incidence of cyclones. In 2010 a quite abrupt change from El Niño to La Niña took place. The heavy rainfalls in Australia at the end of 2010 and early 2011 illustrate how the El Niño/La Niña cycle influences the regional climate.[11]

**Human influence**

Since the dawn of mankind, humans have influenced the climate. First by using fire to burn large patches of forest, later through deforestation for the use of wood, the regional climate was changed. Even now, we influence our regional climate by large scale use of river water for irrigation, by constructing large water reservoirs for hydropower and through the increase of land reclamation and urbanisation. Large cities especially influence the climate around them. Within cities it is much warmer, especially at night, due to the many stones that retain heat. There is also more rainfall above and nearby cities than in rural areas. This is caused by air currents that the warm city generates and by dust particles and air pollution.

Dust particles and air pollution reflect sunlight before it reaches the earth. They also stimulate cloud formation. In general, industrial air pollution has a cooling effect, but there are also forms of air pollution, such as soot particles, that have a warming effect. During the 1960s and 1970s, the effect of air pollution was strong above Europe and North America. Since then, the air has become much cleaner there. Currently, the effect is mainly seen above certain parts of China and India.

**Limit greenhouse gases, raise the dikes or wait and see?**

If we want to limit the risks of climate change, the most suitable strategy is to reduce emissions (exhausts of gases).

Reducing emissions requires different ways of energy production, cutting back on deforestation, and reducing the emissions of methane gas from e.g. cattle, and rice production – all on a global scale. This is not an easy task.

And this is just part of the story, because timely adaptations to the possible consequences of climate change need to be made as well. Anno 2011 the concentration of greenhouse gases is almost 40 percent up from pre-industrial revolution levels. Even if there is a strong international effort for emission reductions, the effects of the additional greenhouse gases currently in the atmosphere are expected to last at least until the year 2100. Should we take climate change into account when making decisions about flood defences, agriculture and nature conservation? If we do this well we will be better prepared, but if we do it wrong, it can lead to unnecessary spending. Hence, knowledge of the future of the climate and of the uncertainties therein has major economic implications.

Is waiting an alternative? Should we wait and see how the climate reacts before we take a decision? By doing so, we take the gamble that things will turn out alright. If it turns out otherwise, we might well come to regret this option. Current scientific insights say that today's emissions will impact the climate and the rise of sea levels in the future. The major part of their impact will be felt 30 to 100 years from now. The difficulty is that 30 years from now it will be impossible to reverse things, if our choices turn out to be wrong.

Climate change is about dealing with risks. And different people judge these risks differently. This also holds true for companies and countries.

**International cooperation**

Because climate change is a global issue, international cooperation is a necessity. The United Nations play an important role in this, even though it turns out that decision making is very complicated at this level.

**FUTURE DEVELOPMENT OF TEMPERATURE**

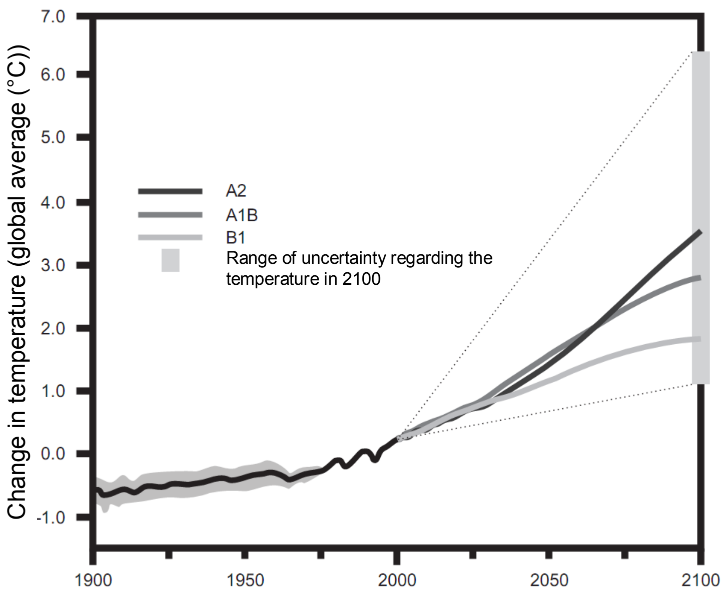



*Figure 5. Projections of the rise of global temperature in comparison to the period of 1980-1999, as given by the IPCC (2007).*[12] *Different future emissions scenarios are displayed.*

In 1992, the first international climate treaty on a United Nations level was signed, later followed by the Kyoto Protocol in 1997. Not all countries participated in this protocol. Especially in the United States there was a lack of belief in the importance of taking measures. The need for government intervention that is implied in reduction efforts led to much resistance there, and in some other countries. Many people also find it difficult to understand that fossil fuels, which have brought us so much wealth, are suddenly frowned upon. The fact that researchers point out uncertainties in their predictions contributes to this doubt. This is part of their job, but in this case it is also due to the nature of the issue. We are, after all, dealing with the future effects of climate change, and the future is uncertain, in this case even more so because we can influence the amount of greenhouse gas emissions. Additionally, as mentioned before, interactions between natural fluctuations and the influence of additional greenhouse gases can never be predicted with certainty.

Due to these kinds of uncertainties, and due to the large interests involved in the energy and agricultural industries, penetrating questions are being asked about the urgency and necessity of policies and measures aimed at reducing greenhouse gas emissions. Such measures affect many interests, such as those of the suppliers of coal, oil and gas, and of the chemical industry and the agricultural sector.

Has the climate issue been sufficiently researched in order to warrant billions of euros in investments? That question is central to the next chapters.

# 2

# *Are climate researchers overstating the problem?*

There is much scientific research being done on the influence of greenhouse gases on our climate. In predicting the future effects, certain assumptions have to be made regarding population growth and economic and technological development. In addition to this, an estimate must be made as to what percentage of greenhouse gases is absorbed annually by oceans and forests, and what percentage remains in the atmosphere. All these assumptions influence the overall results. For this reason, researchers often apply a series of different assumptions to their calculations, to cover the broad field of uncertainties as well as possible. By making different combinations of assumptions, different scenarios are created.

The assumptions underlying these scenarios are motivated choices, but that does not mean they are objective. People who work for an energy company generally have a different view of the future than someone who works for the department of Public Works and Water Management. An ecologist and a meteorologist will undoubtedly have different views yet. The education, experience and background of the people creating the scenarios all play a role in the assumptions they make.

**Models and scenarios**

In their research, scientists make use of models. The models used for 'calculating' the effects of greenhouse gases on the climate consist of a set of formulas, combined with clever calculation methods. The purpose of such a model is to simulate the behaviour of a system, such as the climate system, as accurately as possible. Usually, the system is too complex to account for every variable; in this case, the model will limit itself to simulating the properties that are most relevant to the hypothesis that is tested. Naturally, it is important that no relevant cases and properties get left out of the equation, or the results will be skewed.

These models are developed in a scientific environment. This involves taking measurements, testing hypotheses through experiments and discovering and formulating patterns of behaviour. Experts generally understand the power and the limitations of these models, but outside of expert circles, the results of these models are often judged very differently. It happens frequently that the results of these kinds of model-based calculations are used directly in a political environment without taking into account the assumptions on which they are based.

The scientific debate is concerned with measurable facts; politics is about convincing other people to see things in a certain way. Both factual and emotional arguments play an essential role in this. If research findings are presented without the context of the assumptions and limitations, this can easily lead to misunderstandings.

History reveals that these two worlds, that of science and that of politics, can clash fiercely. In many cases, this is due to a lack of understanding of each other's methods. But clashes also occur when new scientific insights do not support the ideas and ambitions of important parties in society.

The media play an important part in the interaction between science and society. It is not easy for researchers to attract the attention of the media with a nuanced story, because the media as a whole are not very interested in nuances; they want attention-grabbing headlines and one-liners on radio and television. The backgrounds and assumptions underlying the models are usually not keywords that never entirely tell the full story.

Nonetheless, in discussions about climate change the reliability of models is a major topic of discussion. One example that is often brought up is the Club of Rome, and the predictions they made in the 1970s. There has been much criticism of the doom scenario they predicted.

Another example is the discussion during the 1980s-1990s about acid rain. A bleaker picture was painted of the future than eventually came true. A third example is the ozone layer: a problem that arose during the late 1980s. What can we learn from these three phenomena about the results of these models and the role of researchers? And what does this mean for the trust we can place in environmental and climate science?

Below, each of the three examples will be expanded upon. The central question in each case is whether the researchers have exaggerated their findings.

**The Club of Rome**

The Club of Rome is a global think tank whose members include influential people from around the world. The club worried about the effects on the environment of rapid industrialisation, and in the 1960s its members came together regularly. In 1972, the group published the book Limits to Growth, which would go on to sell 12 million copies worldwide. In this report, the group warned about the consequences of unrestrained economic growth such as was happening in the US and Europe at the time. According to the report, continuation and expansion of this trend would lead to grave deficits in resources and food. The perspective of the future that was presented in Limits to Growth was based on the results of research based on models designed by professor Dennis Meadows of MIT (the Massachusetts Institute of Technology) in Boston. He had made model calculations of the use of raw materials and environmental resources in the future. His calculations were based on certain assumptions regarding economic development and technologies commonly in use in 1960-1970.

If the trends in economic and population growth continued, by Meadows' calculations more and more bottlenecks would develop starting around the year 2000. From the year 2030 and onwards, the economy would shrink due to over-exploitation of nature and increasing problems with pollution.

Energy would become scarcer and more expensive, and agricultural yields would decline due to a lack of nitrogen and an overabundance of pesticides. Because of this, food shortages would arise. In short, the growing economy would defeat its own purpose.

The report stirred up fierce debates. On one side stood the supporters of the Club of Rome, who soon gained the name “the no growth community”. On the other side stood the people who were very worried about restraining economic growth with environmental laws and regulations. They trusted that unhindered economic growth, without environmental rules, would eventually produce an answer to environmental problems as well. Now, nearly 40 years later, we can look back. How reliable were these models from 1972?[13]

People who think that climate researchers exaggerate often point to the predictions of the Club of Rome. Because now, 40 years later, reality seems to be less dramatic than they predicted back then. This impression is true up to a certain point: the pollution and exhaustion of resources seems less grave in 2010 than was predicted. Yet, such a conclusion is a bit too simplistic.

When we look back to the models that were used then and the situation in the world as it is now, we must conclude that in those models, not enough thought was given to the potential of technological innovations. Because what happened? In response to the findings of the Club of Rome and other reports from that period, a comprehensive environmental policy was created. In the 1970s, nearly every country in the world established a Ministry for the Environment. Because of environmental regulations and laws and the accompanying development of clean technologies, a “greener” growth started in western countries, a growth in which the economy grows faster than its burden on the environment. Whether that growth is green enough to solve climate change problems and whether this phenomenon will spread worldwide is unsure, because part of the green growth in the affluent west was achieved by relocating polluting activities to Southeast Asia.

In addition to this, environmental improvement did not get started on all fronts. For example, the Club of Rome’s 1972 report warns about the risks of climate change. In this area especially, the Club has done some interesting calculations and presented data that, 40 years later, appear to be almost entirely accurate. This mainly concerns $CO_2$ emissions. On page 70 of the 1972 report is a graph which is reprinted below. To illustrate the accuracy of the predictions, the actual progression of $CO_2$ emissions from 1972 to 2010 is also plotted.

## $CO_2$ CONCENTRATION: CLUB OF ROME PREDICTIONS VS. ACTUAL VALUES

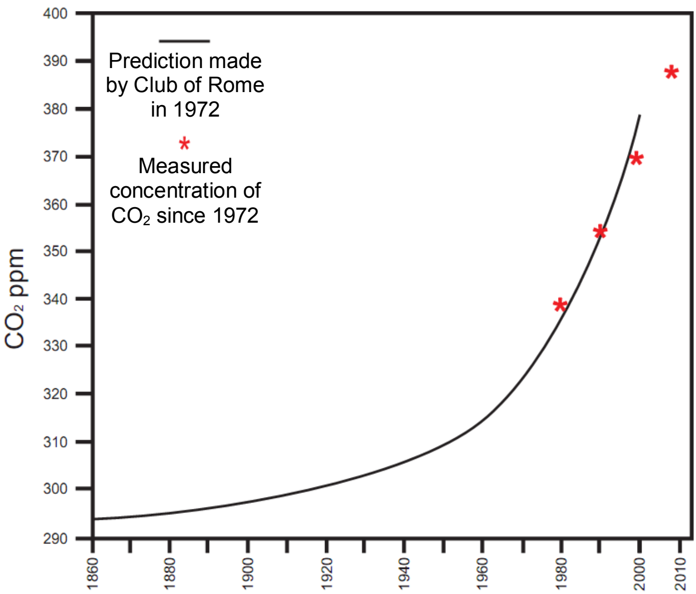



*Figure 6. The predictions made in 1972 regarding the growing concentrations of greenhouse gases by the Club of Rome and the actual measurements up to 2010.*[14]

That exactly this prediction has come true is no coincidence. Many issues highlighted in the Club of Rome's report were taken quite seriously. The issues of chemical water pollution and the use of pesticides in agriculture have been addressed with significant results. Efficient use of resources has, on the whole, increased. But that is less true for the use of fossil fuels. Until recently, cars had a fuel efficiency ratio of 1 litre per 10 kilometres, just as they did in 1972; this only started to change rapidly in recent years. The worldwide efficiency rate of coal plants is not much higher now than it was in 1972, and until the recent introduction of CFL and LED bulbs, lighting was still only as efficient as it was in 1972. While it is true that in Europe a divergence has emerged between economic growth and energy use, meaning the increase of energy use is slower than the economic growth, this was largely achieved by moving energy-intensive industries to other parts of the world. Essentially, this means that pollution has just been moved, not reduced.

In other words: climate change and the effects of $CO_2$ are manifestly stated in the Club of Rome's report, but not much has been done with this in the practice of environmental policy. Not by politicians, but also not by the environmental movements, who were hesitant about pressing the $CO_2$ issue as they feared that their arguments would promote nuclear energy, a technology they feared even more than climate change. It was only with the Kyoto Protocol in 1997 that a start was made on implementing measures to curb $CO_2$ emissions.

Hence the idea that all of the Club of Rome's predictions were too pessimistic deserves some nuance. It is because of the measures taken as a result of this report that many of its predictions for the year 2030 probably will not come true. This effect might be compared to giving an advance announcement of a predicted traffic jam: if everyone responds to the message, the traffic jam will not happen. Does that mean that the announcement was incorrect, or effective?

Another lesson can be learned from the history of the Club of Rome's report. Partly as a result of the report, a strong social movement grew in the 1970s which advocated the curtailing of economic growth and consumerism. This movement gained momentum thanks to two (political) oil crises. Close the curtains, pull on a sweater and travel by public transport: that was the message. According to the champions of this movement, a more austere lifestyle and a conscious decrease in economic production was the only way to keep the world liveable for future generations.

In hindsight, the leaders of this movement overlooked two important factors: they severely overestimated the feasibility of a collective transition to a more austere lifestyle, and underestimated the possibilities brought by technological advancement.

We find these same elements in the discussion on how to approach the greenhouse effect. Even the most environmentally conscious of people will, for whatever reason, want to make the occasional trip by airplane abroad. A substantial decrease in mobility, and thus in $CO_2$ emission from cars, planes and other modes of transport, does not appear to be attainable without a drastic increase of prices, and there is not enough political support for such measures. It is no coincidence that great effort is being put into trying to make transport, including planes, less polluting. For planes, algae-based bio fuels are being developed. Electric cars are being brought to market which are much less taxing to the environment than "normal" cars. The use of these cars will probably eventually be cheaper and more environment-friendly than traveling by (heavy) trains.

What we can learn from this is that humanity's creativity in dealing with environmental challenges tends to be much greater than predicted. Furthermore, our experience from 1970 tells us that environmental measures can be of enormous impact on technological innovation and economic activity. Many measures turn out to generate so much money that investment pays itself back in no time.

Companies that are confronted with the environmental effects of their manufacturing process tend to balk at first; they will argue that they are already doing their bit for the environment, that there are no alternatives, that the alternatives are too expensive, that it will hurt their market position, etcetera. It is only after persistent pressure and regulation that it turns out that much more is possible both technologically and economically than was initially assumed.

**Acid rain**

From the very start of the industrial revolution and continuing until the 1950s, air pollution was seen as strictly a local problem (for example, the infamous London smog) that only affected the immediate environment of the factories and power plants with their smoke plumes. The smoke from the factories and plants blackened nearby homes and buildings and caused breathing problems. White laundry could no longer be dried outside. By increasing chimney height and catching the largest soot particles, these problems were largely solved... or so people thought.

During the late 1970s, scientific research showed, quite unexpectedly, that air pollution caused by the use of fossil fuels led to acid rain even at large distances. Invisible but measurable flue gases (sulphur dioxide, $SO_2$, and nitrogen oxide, $NO_x$) carried high up in the air were indicated as the cause of the acidification of soil and water. From Germany came alarming news of 'dying forests'; substances released by burning fossil fuels (especially coal, which is rich in sulphur) were said to damage the forests' vitality. From Sweden, word came that organic life in the lakes seemed to be disappearing. And in the Netherlands, the fast erosion of limestone monuments, such as the cathedral in Den Bosch, was found to be connected to the high acidity in the air and the rain. On a local scale, the release of ammonia ($NH_3$) from farming played a part as well. By way of rain and gravity, relatively high concentrations of these substances landed in natural areas, which turned out to be sensitive to them. The sulphur particles especially, and to some extent the nitrogen particles and ammonia, were indicated as the cause of acid rain. Some ecologists feared that the cumulative effect of these substances in the soil would eventually lead to the death of all forests.

There was a strong social reaction to this news, especially in Germany, where forests are part of the national identity. Large scale initiatives were started by installing filters in factories and power plants, to catch the acidifying particles before they reached the open air. The Netherlands and the United Kingdom followed their example. The introduction of the catalytic converter on car exhausts was also made around this time. Thanks to billions of euros of investment, the emission of harmful gases has been drastically decreased. This has not only greatly reduced acid rain, but also diminished the negative effects of the aforementioned substances on public health. In the Netherlands, the keeping of livestock attributed to acidification through the emission of ammonia. In the meantime, this sector, too, has made large investments in order to constrain the problem. All in all, the emission of acidifying substances has been more than halved since 1990 (see figure 7). This is a lot, but still less than the 90 percent reduction researchers initially insisted

**DECLINE IN THE EMISSION OF ACIDIFYING SUBSTANCES**

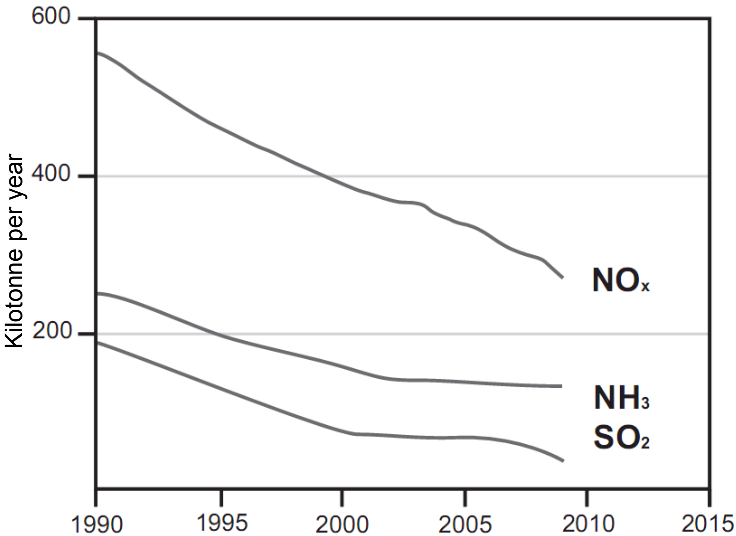



*Figure 7. The decline in the emission of acidifying substances in the Netherlands since 1990. [Source: emission registration[15] ]*

upon.
The acidification is still slowly progressing, but the effects are much less drastic than they were initially presented. There are two reasons why we do not hear much about ‘dying forests’ anymore. First off, the air pollution problem in Europe has been largely solved by the above mentioned technological measures. Secondly, increasing scientific insight has shown that the effects per amount of acidifying substances are less strong than was initially thought. Since 1990, further experiments and fieldwork have shown that the soil and the biological activity in water are more resistant to acidification than was assumed. Initially, researchers concluded that emissions needed to be brought down 90 percent in order to keep acidification within acceptable limits; it was later concluded that a reduction of 70-80 percent would be sufficient to guarantee the vitality of the trees.

In hindsight, we can conclude that the ‘acidic rain’ question was presented as being more dramatic than it turned out. Within a few years of recognizing the problem, the first steps were taken to reduce emissions. While we were still on those first steps, new insight became clear; this happened so fast that no unnecessary costs were made. The forests have retained their vitality, thanks to the applied filters and catalytic converters. On the other hand, ecosystems are still being influenced even today. The soil is much richer in nitrogen than it used to be. As a result of this, biodiversity has decreased in many places, especially in the dunes and on the heaths. Additionally, the acid rain problem has not disappeared everywhere yet (see figure 8 for example).


*Figure 8. The surroundings of the mining town Norilsk in Northern Russia are still affected by acid rain.*

**The ozone layer**

At the end of the 1980s, measurements and scientific research showed that the ozone layer ($O_3$) in the atmosphere was being depleted by gases like CFCs (chlorofluorocarbons). The ozone layer is situated at a height of about 12 to 40 kilometres around the earth and functions as a filter for the carcinogenic ultraviolet (UV) radiation which is emitted by the sun. Without the filtering function of the ozone layer, life on earth would look very different indeed. Humans, certain types of animals and many types of plants are extremely sensitive to changes in this radiation's dosage.

CFCs are released by the usage of spray cans, refrigerators and air conditioners, among other things. Once free, the CFC molecules rise to great altitude and disseminate around the earth. Thanks to the properties of these particularly light substances, they have a profound and long-lasting ozone-damaging effect even in small concentrations. Because of this, people who spend a lot of time outside are exposed to higher amounts of radiation and, as a result, might be more prone to getting skin cancer.

Reports of yearly expanding holes in the ozone layer, first over Antarctica and later over the North Pole as well, followed one another in swift succession during the late 1980s. The ozone layer proved to be thinner in other places in the world as well. At the same time, reports came out that the number of people suffering from skin cancer was rising. Correctly or incorrectly, these two events were linked, which gave rise to strong public support for installing measures to stop the depletion of the ozone layer. Using model calculations, it was demonstrated that even a very small amount of CFCs would lead to extensive and lasting damage. Therefore, scientists recommended a total ban on CFCs.

Initially, this was met with great resistance, especially from the industry that fabricated these substances and kept emphasizing their positive qualities. The industry originally concluded that there were no alternative substances available. Scientists, however, immediately started searching for these alternatives, and found them. Partly because of this, an international decision was made to ban these ozone depleting substances within several years' time (the Montreal Protocol, 1989). Twenty years ago, CFCs were put on the list of banned substances.

Significant investments have been made in order to switch to substances that do not affect the ozone layer. Large funding programmes, run, among others, by the World Bank, enabled developing countries and Eastern European countries to switch to alternatives, even despite their limited finances. These programmes, along with the switch to alternative substances in affluent countries, cost tens of

**HOLE IN THE OZONE LAYER ABOVE ANTARCTICA**

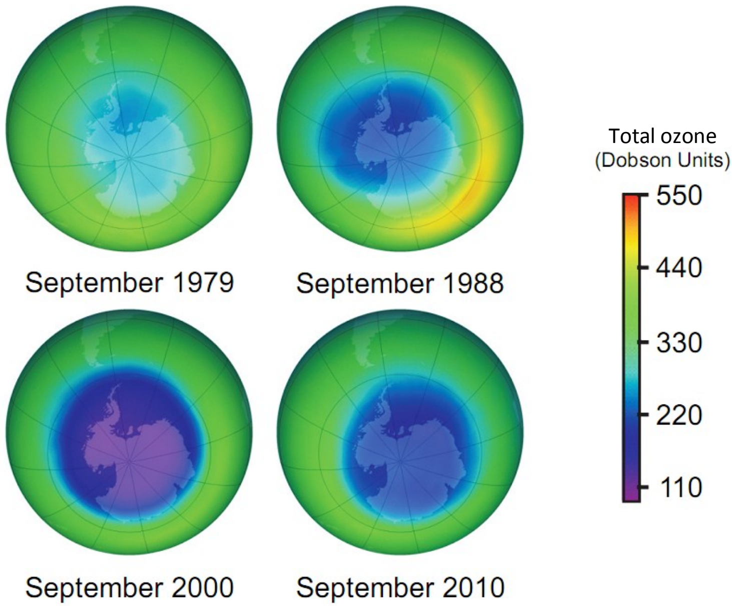



*Figure 9. Examples of satellite images of the thickness of the ozone layer. The first measurements date back to July 1979. These images display the depths as measured in September. The hole in the ozone layer that was measured in September 2010 is less big than in September 2000. [Source: NASA[16]]*

billions of euros, but the effect of these measures is clear (see also: figure 9). CFC emissions have been drastically reduced in the past ten years, and are now almost zero. This means the concentration is no longer increasing, as is evident from the measurements shown in figure 10. Additionally, measurements from 2010 show a slight recovery of the ozone layer. Whether this recovery continues will become clear in the next few years. In any case, it will be decades

**AMOUNT OF CFCs IN THE ATMOSPHERE**

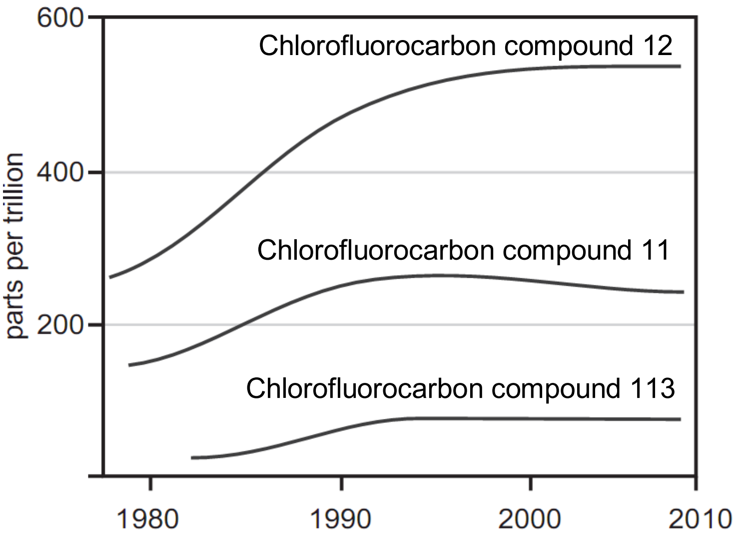



*Figure 10. Average annual concentration of CFCs in the atmosphere above Cape Grim, Australia. The concentration growth has been stopped. The number behind the CFC represents the ratio between the chlorine, fluorine, carbon and hydrogen atoms. [Source: Tasmanian Planning Commission, State of the Environment Report 2009[17]]*

before the ozone layer returns to its original state. Nevertheless, measurements indicate that the banning of CFCs has been a success.
In publications and books published on the issue after the fact, putting a stop to the depletion of the ozone layer has been hailed as one of the greatest international environmental successes of all time. Nobel Prize winner Paul Crutzen stated that we have made a narrow escape by banning the use of the offending substances just in time. What does this mean with regards to our confidence in scientific knowledge of the atmosphere and radiation?

At the time when the ozone layer problem was emerging, it was hard to find conclusive evidence of the harmful effects of the named substances. The only way to an effective solution lay in shared risk awareness and international cooperation. Today, we find ourselves in much the same situation with climate change: now, as then, there are very clear signs but there is no all-convincing evidence, it is a matter of risk calculation, and there is the intention of international cooperation.

Unfortunately, the latter is showing serious signs of struggle. When the problem of climate change was first signalled during the late 1980s, many scientist and politicians, especially in Europe, assumed that this question could be solved the same way internationally as the depletion of the ozone layer: to bring about a gradual reduction in the emission of greenhouse gases through international agreements, and with the help of funds. Reality turned out to be more complicated. The reduction of CFC emissions concerned only a handful of industrial companies with a limited number of factories. The firms producing the banned substances could stay in business by producing the alternatives. In the case of $CO_2$, the stakes are much higher: large amounts of oil, and huge international economic and political interests. These interests are so powerful that the results of scientific research were met with a much more critical reception this time around (see the later chapters in this book). Still, the experience with the ozone layer has proven that the international community is capable of solving these kinds of problems in principle - even when there is no complete certainty.

**The interaction between science and politics**

The leading principle of science is the search for truth. When a researcher thinks to have found a piece of that truth, it will first be subjected to a 'peer review' (meaning it is checked by colleagues from other research institutes), after which it is published in a scientific magazine. The next researchers think they know better, and try to disprove these findings. If they prove successful, it means there was something wrong with the original findings. If they fail, the odds that the first researcher was right improve. Through this process of trying to disprove each other (falsify), knowledge of and insight into the world around us grow.

This is the ideal of self-correcting science. But does this ideal actually work, or do climate researchers knowingly or unknowingly overstate the problem in order to convince those in power? This is the question that is being asked, and it has everything to do with the way science and politics interact.

The example of the Club of Rome shows us that while their predictions for the year 2030 may have been too pessimistic, this is largely because their message was really taken seriously. The analysis presented in Limits to Growth was probably correct, except that the model did not sufficiently account for technological advances. In the case of acid rain it is clear that scientists were initially too pessimistic, but amended their alarming reports when further research showed that less rigorous measures would suffice. In the case of the depletion of the ozone layer, researchers have shown that their models and prognoses provided an accurate representation of the processes in the atmosphere. The concentration of CFCs is no longer increasing, the depletion of the ozone layer has stopped, and the first signs of a tentative recovery are becoming visible.

When the Club of Rome’s report was first presented, as well as when the first reports of acid rain were published, communication between researchers and governments was not very well-organized. It concerned small groups of researchers, from a handful of universities and institutes. Additionally, the media played a (too) significant part in the way the first signs were picked up by those in power. This process was structured during and after the acid rain issue. The manner in which scientists cooperated internationally was structured by the researchers themselves. In cooperation with governments, rules were created for the review and international presentation of scientific results.

During the research into acid rain, researchers from several European countries developed the RAINS model. This model describes the pathways of emissions of sulphur dioxides, nitrogen oxides and ammonia and provides information on their impact in different regions. Thanks to this model, policy makers in different countries all had access to the same data, which contributed to a peaceful solution without countries pointing fingers at one another. At the same time, structured reports allowed different governments to formulate adequate reactions to the results of advancing scientific insights.

During the ozone layer issue, scientists further professionalized their procedures. An international panel was established to facilitate dialogue with corporations and governments. This panel collected scientific literature and made a synopsis using an established set of rules. Industry representatives were part of this panel as well. This attempt to increase support has had a positive influence on international decisions concerning the ozone layer and the banning of CFCs.

These examples show that it is not so much a question of scientists overstating their cause, but of a communication system between science, society and politics that needed (and still needs) improving. The examples above also show that this problem has been acknowledged; since 1972, the organization and presentation of scientific knowledge has become more structured. Concerned companies and governments are becoming more closely involved in the analysis of research data and the presentation of updates on the current state of scientific insights. That there are still some important obstacles to overcome is made clear by recent experiences of the UN's panel on climate change, the aforementioned IPCC. The IPCC's structure and five-yearly international reports have clearly been inspired by the experience gained during the acid rain and ozone layer issues

The question the media and the public are asking is whether the IPCC's reports on climate change in 2007 represented a faithful depiction of the internationally available data. Are the conclusions about the effects of $CO_2$ and other greenhouse gases as shown in these reports fully valid, or were the authors of those reports guided by tunnel vision, as climate sceptics assert? That is what will be discussed in the next few chapters.

# 3

## *How real is global warming when lakes still freeze over?*

In the run up to the international political climate conference in Copenhagen in 2009, the issue of climate change received a lot of attention, and not always in a positive way. In November, just before the conference, the email correspondence of renowned climate researcher Phil Jones from East Anglia University, was hacked and put online. The leaked documents covered 10 years of correspondence and discussions with fellow researchers. From this correspondence, a number of passages were extracted which gave the impression that the researcher in question had made selective use of historic temperature data in order to paint a graver picture of present day global warming than is justified by the facts. The correspondence also gave the impression that there is a closed circle of climate researchers who try to shut sceptical researchers out of the discussion. These allegations were later investigated and disproven in several inquiries, but the die was cast.

At the conference itself, this incident did not receive much attention. There, in Copenhagen in December 2009, the heads of state of over 190 countries reached agreement on a shared goal: to reduce the emissions of greenhouse gases to such an extent that the increase in temperature remains below 2 degrees Celsius. This is a far-reaching goal, which requires making significant changes to our energy supply system: however the participating countries could not agree on how each country should contribute. Many people were disappointed by this, but others rejoiced the lack of decisions on tangible actions. They felt that the scientific case for global warming was not strong enough to justify international action. These critics were strengthened in their beliefs by selected quotes from the aforementioned email correspondence and by the news that some mistakes had been found in the reports of the IPCC: here, too, climate researchers seemed to have exaggerated the effects of climate change.

At this point a storm of reactions broke loose. In the Netherlands, the minister of environment at that time, Jacqueline Cramers, reprimanded climate scientists in a televised appeal. The ministry of environmental affairs made it clear that they would not tolerate any further mistakes in the reports of the IPCC.

At the request of several governments, a further inquiry was conducted into the methodology of the IPCC. In the Netherlands, the planning agency (Planbureau van de Leefomgeving, PBL) checked the IPCC report for errors. The international inquiry was led by an independent committee appointed by the InterAcademy Council. Robbert Dijkgraaf, president of the Royal Netherlands Academy of Arts and Sciences (de Koninklijke Nederlandse Academie van Wetenschappen), was chairman of the Council during this period.

The report of this committee was released in October 2010. The committee concluded that the workings of the IPCC could be improved on several fronts, but also found that the IPCC's conclusions about global warming stood firm. The Dutch investigation by the PBL into additional mistakes also yielded nothing that would diminish support for the report's main findings: that the unabated emission of greenhouse gases is expected to result in a significant change in global climate, and that the warming of the earth over the last 30 years is very likely due in large part to the increase in greenhouse gases.

Several British investigations into the behaviour of the British climate scientist whose email was hacked led to a similar conclusion: there was no evidence that pointed to ill intentions or to the fact that global warming might be less severe than previously portrayed.

This did not completely satisfy the critics, however; a small group of people continued to discredit the findings of the IPCC. They were helped by the rather cold winters of 2009 and 2010 in North America and Western Europe (See figure 11). That, at the same time, the area around Greenland was 10 to 15 degrees hotter than usual, and that the Greenland ice sheet was melting at an unprecedented rate, got far less attention.

*Figure 11. January 2010. For the first time in years, the Dutch lakes froze over. This photo is taken near Monnickendam.*

Why was the public reaction to the flaws in the IPCC report so fierce? In the years preceding the report, the climate story had hit increasingly close to home for citizens and businesses alike. Energy campaigns pointed out people's own responsibility for their contribution to global warming. Many neighbourhoods in the Netherlands organised street parties, featuring initiatives that encouraged people to participate in 'putting a halt' to climate change. In politics, measures such as implementing alternative road taxes and obligatory insulation for houses were discussed. Environmental groups promoted taxes on meat consumption, because the cattle industry is a large contributor to climate change. These proposals stirred up resistance against climate change measures.

When the Dutch cabinet fell over a different matter (support for the Dutch military mission in the Afghan province of Uruzgan), the political decision process about climate policy came to a halt in the Netherlands. Plans for significant investment in sustainable energy were suspended, and plans to improve flood protection systems were re-framed and reconsidered. In October 2010, a new government was formed which seemed to favour the climate sceptics' view on affairs; the words climate change were not mentioned once in the new coalition agreement.

Altogether, one could say that Dutch political support for climate change measures made a U-turn in 2010. While findings of climate researchers and institutions like the Royal Dutch Meteorological Institute (KNMI) had been taken seriously for over 20 years, the new government suddenly became very sceptical regarding everything that has to do with global climate.

**Is it really getting hotter?**

In early 2010, climate sceptics presented data from weather stations across the United States, which showed that the average temperature had gone down, rather than up, since 1998. They used this as evidence to support the theory that global warming has halted. The warming we had seen until now was supposedly due to cyclical behavioural patterns of the sun; with the sun reaching the next phase in this cycle, the earth was now cooling down again and had been since 1998.

Several remarks need to be made about these 'findings'. It is true that global average temperatures reached a record high in 1998, and have not sur-passed that same level since then. However, looking at each year individually, and then comparing the period 1990-2000 with 2000-2010, gives a very different impression.

The average temperature measured on a year-by-year basis is shown in figure 12. When we look at the years from 1998 to 2009, without considering the years before then, we get the impression that global warming has indeed come to a halt. This reasoning is as valid as observing that sea levels are dropping during a walk along the coast shortly after high tide.

**PROGRESSION OF GLOBAL TEMPERATURE 1900-2010**

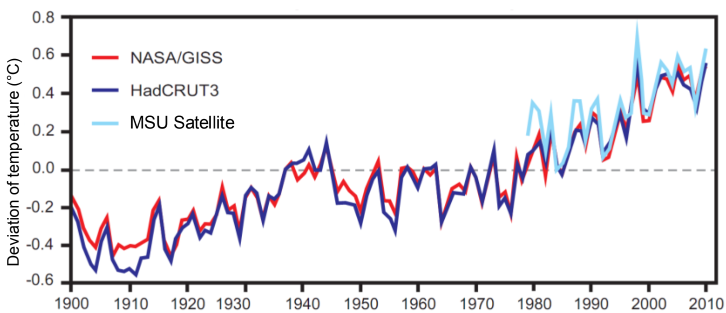



*Figure 12. Deviation of global average temperatures as compared to the average over 1961-1990, obtained through different measuring methods. Data from NASA, the Hadley Centre and the MSU satellite [Source: KNMI[18]]*

The climate sceptics evaluated a period that was too short. The start of this period was chosen rather selectively, by starting with the hottest year ever measured. Evaluating the average temperature of ten year periods yields a more representative image. A ten year period also comes closer to the definition of climate, in which we tend to consider periods of thirty years. This average temperature and its margin of uncertainty are displayed in figure 13. These are the same observations as in figure 12, but displayed as ten year averages. The results show that the earth is indeed heating up, with some 0.15 to 0.2 degrees every ten years.

**AVERAGE TEMPERATURE PER DECADE**

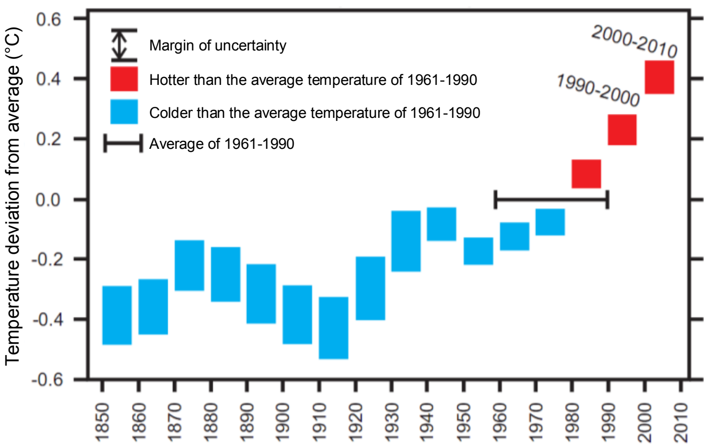



*Figure 13. The bars show the average global temperature per decade, compared to the average temperature of 1961-1990. The height of the bar shows the margin of uncertainty. [Source: NOAA 2010[19]]*

## The effect of the sun

Despite this evidence, a small group of scientists continues to support the idea that the sun is the most important source of recent warming, pointing out the natural cycles in the intensity of sunspots. The sun's activity follows a pattern with a cycle of (approximately) eleven years. This pattern can, to some degree, be found in historic data regarding hotter and colder years. Failed harvests, and the revolutions that followed them, in eighteenth and nineteenth century Europe are often matched to the sunspot pattern by historians.

Research on the relation between solar activity and the earth's climate also indicates the existence of natural cycles in solar activity with longer periods, one of 90 years and one lasting 200-250 years (remember figure 3 in chapter 1). These patterns are more difficult to recognize because of their irregularity. There are strong clues, however, that they cause significant changes in the average temperature in some parts of the world.

The longest cycle is thought to be responsible for the warm period around the year 950 AD, when the Vikings settled Greenland. The colder period known as the Little Ice Age (painted by Avercamp, in figure 14) is also mentioned in connection with this pattern. The long cycle and its influence on the average temperature are ambiguous and therefore not universally acknowledged.

Geologists have found clues that point to the existence of even longer cycles, one of 1,500 years and one of three to five thousand years. These cycles have also been connected to variations in solar activity.

*Figure 14. Hendrick Avercamp painted Winterlandschap met IJsvermaak (winter scene with ice skaters) in 1608, in the period that is now known as the Little Ice Age.*

Techniques for reconstructing our geological history have improved drastically over the last decades. Examples of modern techniques include isotope analysis of silt samples taken from lake beds and ocean floors, studies of coral reefs, studies of the development of stalactites in caves and analysis of the composition of air found in small pockets in icecaps through deep drilling operations. Due to these much more accurate measurements, it has become possible to make fairly accurate reconstructions of the course of temperature, air composition, the age and origin of seafloor materials, and sea level.

Through such geological reconstructions and by combining data from different sources, climate researchers have acquired more insight into the processes that influence our climate and climate change, including the effect of variations in solar activity.

The IPCC reports also discuss the influence of the sun's activity at length. Both in these reports and in other scientific publications, it is reported that although variations in solar activity (including the longer cycles of two hundred years and more) influence the average global temperature, this influence is limited to around 0.2, up to a maximum 0.4 degrees Celsius. Certain parts of the world, like North West Europe, may have experienced a stronger influence, but when considering the earth as a whole, scientists cannot find proof of an influence larger than 0.4 degrees.

A variation of 0.2 to 0.4 degrees due to fluctuations in solar activity is not negligible if we compare it to the temperature increase in the last hundred years, which is 0.8 degrees. But when we compare it to the expected influence of increased concentrations of greenhouse gases over the next hundred years, indicated to be between 2 and 6 degrees, it is relatively small. In other words: even if the activity of the sun could lead to some amount of cooling during certain periods, the effect would be far too small to compensate the effect of greenhouse gases. Furthermore, the cyclical behaviour of the sun means that it will contribute to global warming during other periods.

**The 'fingerprints' of the sun and greenhouse gases**

In 1990, the IPCC published its first calculations of the predicted rise in temperature as a result of additional greenhouse gases. Since then, the earth has warmed up by

0.3 to 0.4 degrees, which corresponds with these predictions – see figure 16. This could be a coincidence, but that is not very likely. And it would be very coincidental indeed if the exact amount of warming that was calculated to be caused by greenhouse gases was instead caused by solar activity.

There is another sign that the sun is not responsible for the measured warming of the earth. This sign can be found in the pattern of warming that is measured around the globe. The earth is heated by radiation from the sun. When this radiation increases, it affects the temperature in different atmospheric layers and in the oceans according to a specific pattern. When volcanic eruptions affect temperatures, this effect follows a measurably different pattern. Industrial air pollution also has its own distinct pattern. You could say that each source of global warming has its own fingerprints. This also holds true for greenhouse gases.

The way additional greenhouse gases contribute to the warming up of the earth is by inhibiting thermal radiation (infrared) from the planetary surface toward the universe. Moving up from the earth, this radiation meets with heavier resistance than it used to, due to the presence of additional greenhouse gases. As a result, the lower atmospheric layers heat up. But because of the reduced throughput of heat, the upper atmospheric layers actually receive less heat, while they continue to emit heat into the universe. The net effect of this is that the upper atmospheric layers get colder. This pattern is distinguishable from other influences on temperatures. Because of this, we can differentiate the effect of greenhouse gases from other effects such as solar activity, volcanoes and air pollution.

The way temperatures have developed as measured over the last hundred years is shown in figure 15.

This shows that, especially during the last thirty years, the lower atmospheric layers have warmed up while the upper layers have become colder. This pattern indicates a dominant role for greenhouse gases in the increase of the average temperature at the earth's surface.

**TEMPERATURE IN THE ATMOSPHERE**

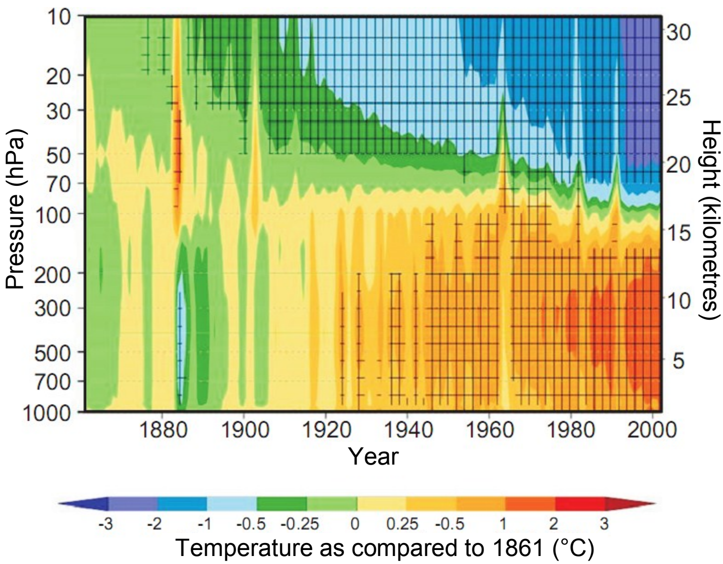



*Figure 15. Global average atmospheric temperatures since 1861. All known causes (human and natural) of warming have been included. The graph shows that the temperature in*

*the higher spheres decreases, while the temperature in the lower 15 kilometres is rising. The shaded area reflects areas for which the change in temperature cannot be wholly explained by natural phenomena like solar variation and volcanoes. In those areas, the effect of additional greenhouse gases is very likely to be the main driver of change. [Source: Schwarzkopf & Ramaswamy,* Geophysical Research Letters *(2008)[20]]*

No matter how convincingly the increase in temperature is measured, nor how recognizable the pattern is, the discussion about how to interpret the data remains. Supporters of the idea that the sun is the main driver behind the last decades' warming point out that not all aspects of the temperature pattern show the same development, and state that you can never entirely exclude the possibility that variations in solar activity could have a different impact than is currently thought.

**What the IPCC said in 1990 about temperatures in 2010**

As mentioned before, it has now been over twenty years since the first calculations of the impact of greenhouse gases were published by the IPCC. These indicated that temperatures would rise by 0.15 to 0.2 degrees per decade in the years to follow. Figure 16 shows the predictions made by the IPCC in 1990. Now, in 2011, we can compare these predictions to the actual changes in average temperature that have occurred since then.

**THE IPPC PREDICTION IN 1990**

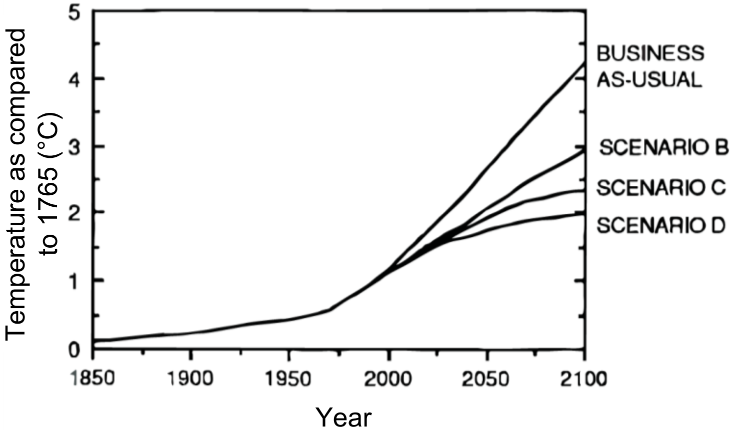



*Figure 16. Results of the calculated average temperatures for the period 1990 to 2100 under different emission scenarios, as shown in the IPCC report of 1990.*[21]

Figure 17 shows the actual measurements. It shows that the increase in the average temperature from 1990 to 2010 is 0.3 to 0.4 degrees, which matches the predictions made in 1990. It is important to consider that the effect of increased concentrations of greenhouse gases on global temperatures lags behind, just like in a room where the heating is turned up. The radiators immediately start to produce more heat, but it takes a while to warm up the space and the objects in it. Similarly, it takes up to 30 to 50 years before the average temperature of the earth has adjusted to higher levels of greenhouse gases. This means that the current average temperature mainly reflects the emissions of, and changes in, the concentration of greenhouse gases that occurred the last 30 to 50 years. It also implies that temperatures will continue to rise for quite some time, even if the concentration does not increase further.

With the IPCC's predictions proving accurate, climate scientists expected confidence in their work to increase. Much to their surprise, they met with a wave of criticism

**THE IPCC PREDICTION IN 1990 AND THE ACTUAL CHANGE IN TEMPERATURE**

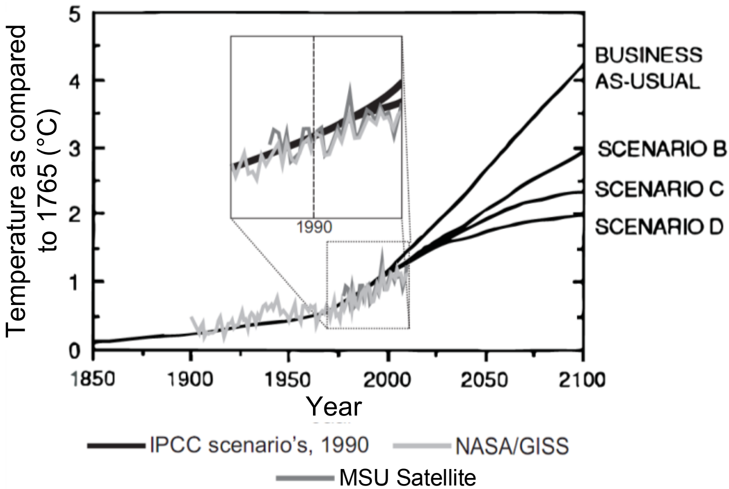



*Figure 17. The underlying black lines are the projections of temperature change made by the IPCC in 1990, on which the actual measurements from 1860 up to now are superimposed in grey. The figure clearly shows that the measured temperature increases with the same speed as was predicted in the IPCC's 1990 report. [Sources: IPCC and KNMI[22]]*

instead. The irony is that while measurements increasingly strengthen the scientific foundations of the climate researchers' calculations, criticism of their work seems to become fiercer.

The discussion about (the changes in) temperature reveals that local weather conditions, for example a relatively cold winter strongly influence public opinion on global warming. However, a wider view shows that the temperatures around the North Pole are rising rapidly.

**CHANGE IN THE VOLUME OF ICE AROUND THE NORTH POLE**

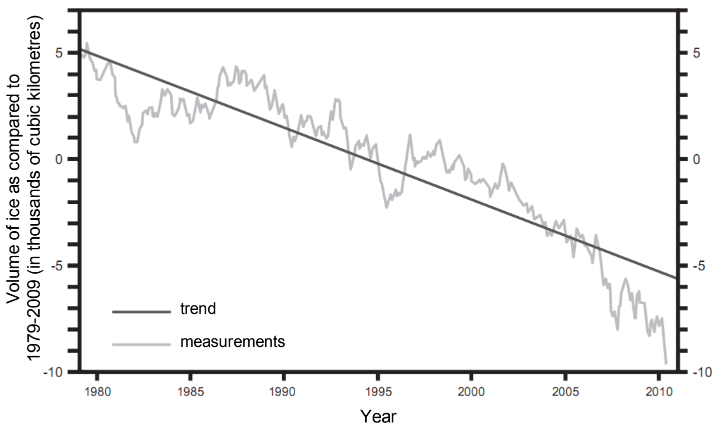



*Figure 18. The decline in the volume of sea ice in the area around the North Pole in thousands of cubic kilometres, compared to the average of 1979-2009. The straight line indicates an average loss of 3400 cubic kilometres per decade. [Source: NSIDC 2010[23]]*

This is also evident in measured changes in sea ice in the Arctic Ocean and recent data on the melting of the Greenland ice sheet. The decline of the ice volume in the Arctic Ocean and the decline of the sea ice surface at the end of summer (September) are displayed in figures 18 and 19. Trends around the South Pole are less clear.[24] However, recent measurements indicate a net loss of ice. The change in the average temperature of the earth as a whole over the last 30 years is displayed in figure 20.

**ARCTIC ICE SURFACE CHANGE SINCE 1980**

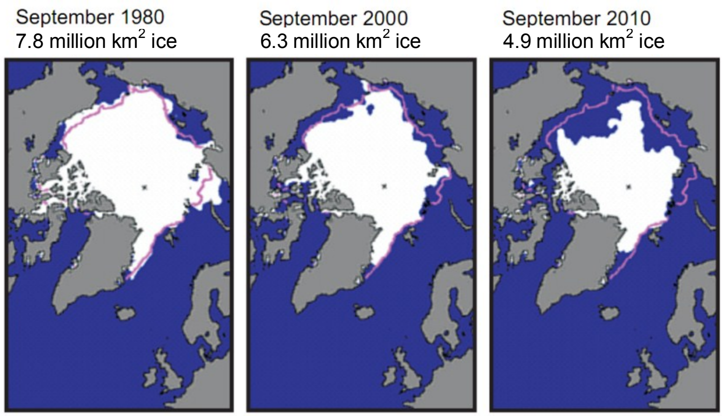
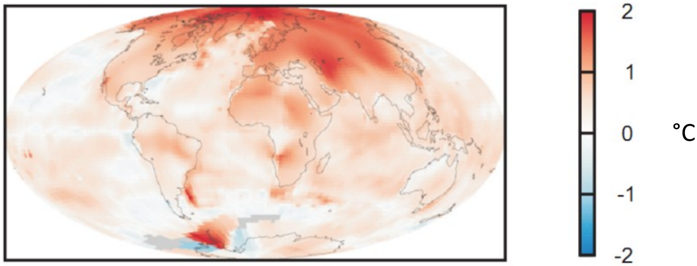



*Figure 19. Surface area covered by arctic ice in September 1980 (left), 2000 (mid) and 2010 (right). The pink line represents the median for 1979-2000. [Source: National Snow and Ice Data Center[25]]*

## NASA MEASUREMENTS 2000-2009, COMPARED TO 1950-1980




## IPCC SCENARIOS FOR 2100 COMPARED TO 1980-1999

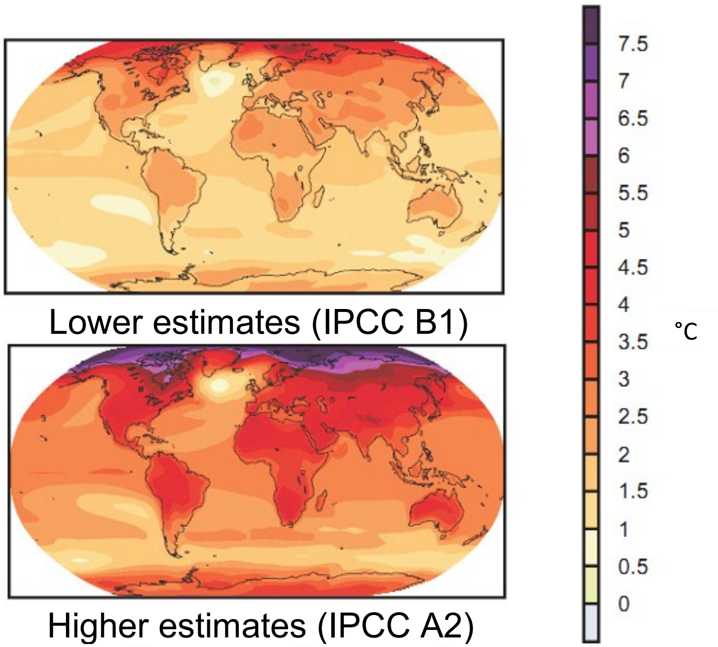


*Figure 20. The top image shows the increase of average temperatures measured over the period 2000-2009 compared to average temperatures during 1950-1980. The image in the middle shows projected temperature increases for the year 2100 for a scenario in which greenhouse gas emissions are relatively low. The bottom image shows projections in case of high emissions. [Sources: NASA and IPCC (2007)[26]]*

# 4

# *Is human influence on our climate being overestimated?*

Research into climate change is being done in different scientific disciplines, one of which is geology. Several geologists strongly downplay the importance of human influence on climate. While they agree with the IPCC's conclusions on the increase in greenhouse gases and the causes thereof, they do not believe that these additional greenhouse gases could have a significant impact on global climate. They refer to the earth's geological history, when changes occurred in our climate while there was barely any human population on earth. They argue that the earth's average temperature has its own dynamic: solar variation, variable ocean currents, volcanoes and ice ages caused by the tilt of the earth's axis each play their own part. According to them, human influence cannot compete with these forces of nature.

However, the majority of geologists who are doing research into past climate variations are extremely concerned about the effect of additional greenhouse gases. Their research, aided by accurate isotope analysis, shows that greenhouse gases like $CO_2$ and $CH_4$ (methane gas) played a significant role in past climate variations. We will examine this more closely in the section on ice ages, but first, let us put things into perspective.

Something that tends to annoy geologists is the slogan “Stop climate change”. This slogan, often used by the environmental movement, betrays a certain overconfidence. Of course we do influence the amount of additional greenhouse gases through our behaviour, but the impact this has on our climate is indirect. Besides, once the climate has changed, this change lingers on for a long time. It remains to be seen whether reducing emissions would bring us back to the ‘old’ climate. The UN treaty on climate change therefore does not aim for the stabilization of our climate, but it aims for the stabilization of the amount of greenhouse gases in the atmosphere by reducing emissions caused by human activities. Indeed, we can reduce the influence of our activities on global climate, but that will not have a one-to-one effect on the climate itself, because human influences interact with natural climate variations. Important questions we need to ask ourselves are: to what extent can we adjust the influence we have on our climate? How effective could such a reduction be, and can we define the limits of our influence? What can we learn from past climate dynamics? These are questions that science is now focussing on.

**Ice Ages**

Since about three million years, earth’s climate has been characterized by regularly recurring ice ages. The pattern of these ice ages and their relation to the tilt of the earth’s axis were first described by the Serbian engineer and geophysicist

Milutin Milankovitch in 1941. Since then, the variables causing this pattern have been known as the Milankovitch cycles. What is of interest to our present situation is the fact that during these cycles, a strong parallel exists between temperature changes and changes in the concentration of greenhouse gases in the atmosphere. The ice ages and their accompanying shifts in the concentration of greenhouse gases occurred without any human influence; there were barely any humans on earth when ice ages first occurred. We are currently in an interglacial period. According to Milankovitch's pattern, the next ice age will begin in about 20,000 years.

An ice age happens as follows: it starts with a small change in the tilt of earth's rotational axis. This change causes the Northern Hemisphere to receive slightly less energy from the sun. This territory cools down, and snow and ice spread across a larger area. Due to the increasing whiteness, a larger portion of sunlight is reflected back, which cools the area down further. This self-reinforcing process leads to an ever-growing expansion of the icecap, eventually extending all the way to mainland Europe. When, at a certain point, the axis tilts back to its original position, the Polar Regions get more sunlight and the ice begins to melt. The sea and land become darker and thus absorb more sunlight. This makes the temperature rise even further, until the snow cover and the icecaps are the size we are now used to.

## TEMPERATURE AND $CO_2$ CONCENTRATION ON A GEOLOGICAL TIMESCALE

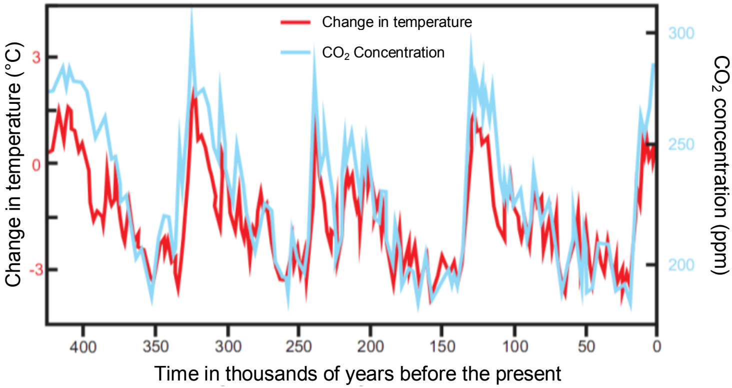



*Figure 21. Changes in temperature and concentration of greenhouse gases during the last 450,000 years. Between ice ages and warm periods, the temperature has fluctuated by about 6 degrees Celsius. The $CO_2$ concentration ranged from about 180 to 280 parts per million (ppm). [Source: Hansen et al., The Open Atmospheric Science Journal (2008)[27]]*

This is quite a simple explanation of a complicated process, in which other (geological) processes also play a part, like the change in concentration of greenhouse gases (more on this later), and the effect of the changing weight of icecaps and the compression of the earth beneath that weight.

The course of the ice ages, the changes in temperature and the concentration of greenhouse gases can be reconstructed with increasing accuracy by measuring the changes in composition of the air locked inside old icecaps, and by the change in the isotope ratio of oxygen trapped at the bottom of the ocean. The reconstruction is shown in figure 21.

The temporal accuracy of the reconstruction from the distant past is limited. For that reason, it is hard to tell which came first: the increase in temperature, or the increasing amount of greenhouse gases in the atmosphere. The scientific community has argued over this “the chicken or the egg” question for many years. Thanks to the improved methods of analysis in laboratories, our insight has grown significantly. Presumably, it goes as follows: the warming up after a cold period starts with a small tilt to the earth’s axis. This increases the amount of energy the earth receives from the sun. This makes a certain amount of snow and ice melt, warming the land even more and allowing more greenhouse gases to escape into the atmosphere. Because of this, the earth heats up even more. This process continues until the earth’s axis is back in its original position. Then it turns colder again, the amount of snow and ice increases, and more greenhouse gases get trapped in the soil.

We are talking about self-reinforcing processes: a warmer earth produces more $CO_2$, and more $CO_2$ leads to more warming. Which leads us to the question: why is the earth not boiling hot? The answer is that these kinds of self-reinforcing processes only work within certain limits. When that limit is crossed, the process enters a new phase. Or –as in the case of the ice ages- the self-reinforcing process stops because it is disrupted by other geological processes, like the regularly recurring tilting of the earth’s axis. Our knowledge of these kinds of self-reinforcing processes and the limits within which such self-reinforcement can operate within earth's system is still limited. The interaction between geology and earth's biology is so complex that predictions lose their worth when we step outside the boundaries of our knowledge.

According to a number of climate researchers, the process of self-reinforcement in both directions is the most plausible explanation for the extreme temperature differences between an ice age and an interglacial period. It starts with a small change to the tilt of the earth's axis, but it is reinforced by what we call 'feedbacks'. Positive feedbacks are processes that reinforce an initial change; negative feedbacks are processes that deter that change. At the start of an ice age, an initial cooling is reinforced in two ways. Because of a small decrease in temperature, the snow cover grows. At the same time, in this colder world, the flow of greenhouse gases into the atmosphere decreases, as a result of which the concentration of greenhouse gases declines. Because of this, the temperature falls even further. These two reinforcing processes, change of reflection and change in greenhouse gas emissions, are responsible for the fact that the difference in temperature between an ice age and an interglacial period is much greater than is calculated by the variation in the amount of sun energy reaching the earth by the tilting of the earth's axis alone. When we calculate the temperature change that would occur due to this last variation, this would be much less than 0.1 degree, while the actual temperature change during a full ice age cycle is about 6 degrees Celsius. The two reinforcing processes taken together are practically solely responsible for this 6 degree temperature difference. The tilting of earth's axis is nothing more than a periodical trigger; other processes do the actual work.

An estimated half of those 6 degrees of temperature difference is caused by the change in the reflection of earth's surface, the so-called ice-albedo feedback (see figure 22). The other half is associated with the change in the concentration of greenhouse gases during the coming and going of the ice ages. The $CO_2$ concentration in the atmosphere during an interglacial period and during an ice age varies between 180 and 280 ppm (*parts per million*, parts of $CO_2$ per million parts of air), see figure 21. The 100 ppm difference in this case means a change in temperature of about 3 degrees Celsius. This theory has been described in scientific terms by the NASA-affiliated American climate researcher James Hansen in 2008.

The relationship between the concentration of greenhouse gases and temperature is not linear, but logarithmic. This means that an increase of the amount of greenhouse gases has a progressively smaller impact on temperature. If we take this into account, we can calculate the effect that the increase in greenhouse gases will have on the temperature increase in the year 2100. This leads us to the conclusion that, if greenhouse gas emissions continue to grow, the average temperature on earth will grow by more than 4 degrees Celsius. Not all geologists agree with Hansen's reconstruction. They point out that other effects can also play a part, like storms that stir fine sand up into the air, thereby partially blocking the sun's radiation.

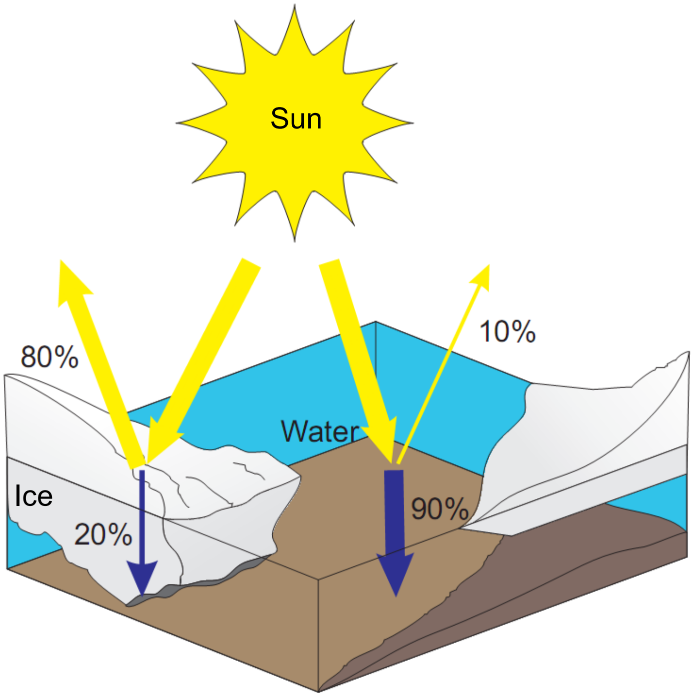



*Figure 22. Increased temperatures cause snow and ice around the North Pole to melt. This increases the rate with which this area warms up, because water reflects only 10 percent of the incoming heat, while ice reflects roughly 80 percent back into the atmosphere.*

**Greenhouse gases and heating**

Hansen took into account more than just the ice ages. He also analysed all the work done by geologists in reconstructing the behaviour of the icecaps, of climate and the concentration of $CO_2$ in the atmosphere, and has charted the development of these magnitudes over the past 110 million years as well as possible. In doing this, he discovered a clear relationship between these variables.

Hansen's conclusion is that the melting of the icecaps in Greenland and Antarctica in the geological past has always started when the concentration of greenhouse gases rose above 350 ppm. In comparison, the current concentration of $CO_2$ in the atmosphere is 390 ppm; if we add in the other greenhouse gases, the $CO_2$ equivalent of that total would be 460 ppm. This means that the critical limit of 350 ppm as named by Hansen has been exceeded for more than a decade. According to him, it is no coincidence that the icecaps have been melting much faster these past ten years than they have in the hundreds of years previous.

Like others, Hansen points out that while these kinds of processes start out slowly, they also take a long time to stop. He states that only a drastic worldwide reduction of greenhouse gas emissions can stop the melting process.

**The carbon cycle**

Thanks to the naturally present greenhouse gases in the atmosphere, the average temperature of the earth is approximately 15 degrees Celsius. Without these greenhouse gases, the earth would be 33 degrees colder. Historically, the naturally present concentration of greenhouse gases has not been constant; there have been periods with much higher concentrations, tens of millions of years ago. The average temperature on earth back then (30 to 60 million years ago) was much higher than it is now. Over the past few million years, the concentration of $CO_2$ has been fairly constant, be it that the ice ages show a pattern within which concentrations vary from 180 ppm in the coldest periods to 280 ppm in the hottest periods; see figure 21. Ever since the industrial revolution and the accompanying use of fossil fuels, the concentration of $CO_2$ has been increasing (see also figure 42 in chapter 8). Once $CO_2$ is present in the atmosphere, it stays there for about a hundred years. This means that one molecule of $CO_2$, once free, spends about a hundred years in the atmosphere as a greenhouse gas. This means that the greenhouse gases emitted as a result of human activity will continue to influence our climate for hundreds of years.

Figure 23 illustrates the carbon cycle. The C in $CO_2$ stands for carbon. This figure depicts carbon stocks as well as the flows between the oceans, the soil and the atmosphere. The numbers in this figure show that each year, some 120 gigatonnes of carbon is exchanged between the atmosphere and the earth's soil and vegetation as a result of natural processes. Somewhat more of it comes down than goes up, because the concentration in the atmosphere is higher than it used to be. Additionally, 90 gigatonnes of carbon exchanges yearly between the oceans and the atmosphere.

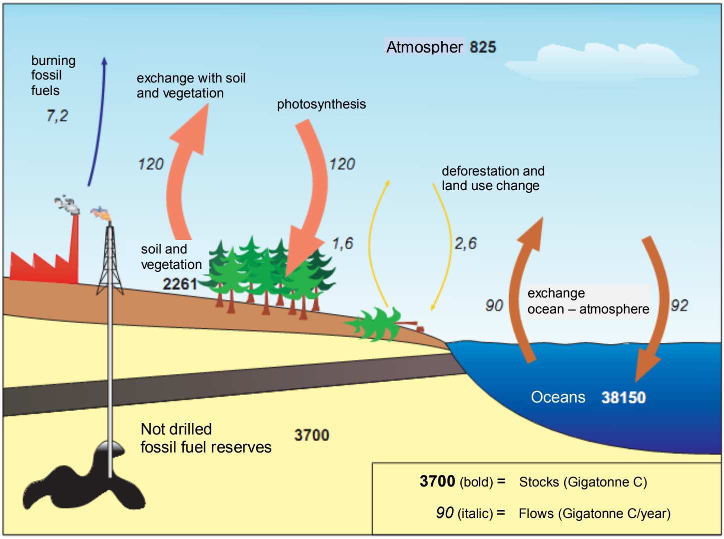



*Figure 23. This figure shows the key components of the carbon cycle. The width of the arrows corresponds with the size of the flows. The largest carbon stores are also depicted. [Source: IPCC, 2007[28]]*

Here, too, more is taken up than is emitted, due to the overabundance of carbon in the atmosphere. The figure shows that approximately fifty percent of the amount of carbon released yearly by human activity is absorbed by the soil, the vegetation and the oceans. The other 50 percent cannot be absorbed so quickly, and remains "hanging" in the atmosphere.

The figure also shows that the yearly flow of carbon ($CO_2$) between the earth and the atmosphere is much greater than the yearly flow that is caused by human activity. The latter comprises approximately 9 gigatonnes a year, 7 of which stem from the use of fossil fuels. As a result of this, one might conclude that human influence is relatively small. After all, a small change in the natural flow seems to have the same kind of influence as all human activities taken together.

However, this reasoning is faulty. The natural flows are all balanced against each other, while the flow caused by human activity amounts to a net addition of greenhouse gases to the system. Because of this addition, the concentration in the atmosphere has grown by approximately 40 percent in the past 100 years (from 280 ppm to 390 ppm), as measurements show.

**Can the warming effects be compensated by an imminent ice age?**

An important question that is asked regularly is whether the current warming of the earth could be compensated by a future ice age. This is an interesting thought. The amount of warming calculated now could, in a worst case scenario, rise to an increase of 6 degrees Celsius. In the coldest phase of the ice ages, the average temperature was about 6 degrees lower. However, while these two temperature differences are the same, they cannot be scored out against each other, because they occur over completely different timespans.

The coming and going of an ice age takes place over a period of over 100,000 years. The next ice age is expected to start in approximately 20,000 years, and as previous cycles indicate it will take some 20,000 more years before the earth cools down by 6 degrees. The current increase in temperature caused by greenhouse gases takes place in a timespan of decades or centuries. It is therefore not very realistic to count on a coming ice age to compensate for the warming up during the next hundred years.

**Volcanoes**

Volcanoes played a significant role in the building of the atmosphere. Through their activity, a lot of $CO_2$ was brought into the atmosphere in the distant geological past. These days, volcanoes still play a part, but their influence on climate is of a more temporary nature. The eruption of the Krakatau near Java on August 27 1883 is an example of this. After this eruption, there were some exceptionally cold years and there was worldwide crop failure and famine.

The current influence of volcanoes does not concern $CO_2$, but rather dust, which contains sulphur compounds among other things. This dust rises to a height of about 10 kilometres. At that level, it can block the sun’s radiation to a certain extent, with cooling as a result. After several years, the influence of such an eruption has run its course. The dust particles which have been flung into the atmosphere descend over the course of a few years and are washed away by rain.

A recent example is the eruption of the Pinatubo in the Philippines in June of 1991. The average temperature on earth in the following year was lowered by about 0.2 degrees. A few years later, the effect was gone. The influence of one single volcanic eruption can be as significant as a ten-year rise in greenhouse gases, but the effects of ten years of $CO_2$

emissions will be felt for a much longer time, about a hundred years longer.

# 5

## *How bad would it be, a slightly warmer world?*

The consequences of climate change are usually portrayed gravely, but there are definitely benefits to it as well. Being outside in the early spring is something that most of us will be able to appreciate. Or, on a more serious note, longer growing seasons lead to higher agricultural yields, while softer winters mean lower heating bills. In times of cold weather one can often hear people sigh: where is this supposed global warming?

This is an understandable question, but it does not take into account the inertia of the climate system. Changes in climate take time to manifest themselves. Once they are started, however, it is difficult to stop them. Global warming takes time, especially with the vast quantities of water in the oceans. Once started, the processes of warming and rising of sea levels will keep going for centuries.

The most important question, therefore, is: how do the dynamics of society and the dynamics found in nature relate to the speed with which our climate is changing? Can we adapt sufficiently and in a timely manner, or will we be surprised time and again? The answer to this question depends largely on the speed with which our climate changes. Are we dealing with a 1 degree increase by the year 2100, or will temperatures rise by as much as 6 degrees?

Some areas will face stronger increases than the world average, and in other areas the change will go slower. This depends among other things on the proportion of land and sea surface in the area, and on the dominant ocean currents. Changes in wind patterns will also contribute to large differences in the amount of warming across the globe. In some areas climate change will be exacerbated because the surface will become darker when the snow melts. Other places could see an influx of cold air or an increase in cloud cover, which will reduce warming. Figure 20 (at the end of chapter 3) depicts differences in warming up to the present day, and shows how large these differences could become under different scenarios with low and high increases in temperatures as predicted by the IPCC.

The answer to the question of how serious climate change is depends on three things. Firstly, the speed and the magnitude of change are important. Secondly, the adaptive capacity of mankind and nature matters. Thirdly, our sense of justice plays a part: to what extent will the people who suffer the consequences of climate change be willing to accept the fact that these changes were caused by people in other parts of the world? This is a sensitive issue in international politics, especially since greenhouse gas emissions so far have mainly been produced in the richer countries, while poorer countries stand to suffer the most, because they have little funds available for timely adaptations.

The impact of a rise in global average temperature of 1 or more degrees by the year 2100 will be described in the next paragraphs.

**What to expect from a 1 to 2 degree increase?**

If the global average temperature increases by 1 degree by the year 2100 we will be able to adjust reasonably well, as will nature. The amount of change to our climate under this scenario is comparable with the amount of change we are currently experiencing; anno 2011 the average global temperature is roughly 0.8 degrees higher than it was a hundred years ago. Spring would start several weeks earlier and winters would, on average, be milder. Average precipitation would increase, with heavier downpour, especially during the summer. We would see more prolonged periods of drought.

By and large, this holds true for most regions in the world. As a rule, areas with a lot of precipitation would see even more precipitation, while dry areas would become dryer still. Furthermore, sea levels would rise with greater speed than before. The Northern Hemisphere would warm up faster than the Southern Hemisphere, because it has a greater land mass.

Certain areas would benefit from global warming, for example Canada, North West Europe and the northern parts of Russia. Agricultural yields would improve in those areas because of a prolonged growing season and milder winters. Sea traffic between Europe and Asia over the Northern Sea Route could become possible during summers: the route that great explorers like Willem Barentsz have long searched for, but never found because they stranded in Arctic Ocean ice. At the same time, areas in the far north would face partial melting of permafrost. Roads, oil pipelines, houses and other buildings in these areas would need new foundations in order to avoid collapsing.

Other areas, such as southern Europe, North Africa and areas in similar climate zones across Asia and the Americas, would face problems caused by reduced rainfall and hotter summers. The patterns of rainfall will also change, leading to more failed harvests.

The speed with which the earth warms up is not the same in all areas. In the Netherlands, for example, temperatures have risen slightly faster than the world average. This is caused by indirect effects; because the earth warms up (as a result of greenhouse gases) wind patterns change, meaning in this case that more warm air is brought in. Temperatures in the Netherlands are expected to continue to warm faster than the world average, but this is not entirely certain. Because the country is situated by the sea, a small change in the predominant wind direction can have a large impact on the temperature.

If temperatures rise by 2 degrees, the consequences are still foreseeable up to a certain point, even though heavy damages can be expected across the globe and large investments will have to be made in order to make the necessary adaptations. The benefits and disadvantages will be spread unevenly among countries. Large ecosystems will be hard pressed to adapt to new circumstances, and this will probably not succeed everywhere. In some places, massive dieback will take place. A number of species of plants and animals will go extinct.

Temperature-sensitive ecosystems like ice sheets and coral reefs will come under severe pressure in many places. Rainfall and droughts will intensify and change geographically. This will result in more failed harvests. The consequences for a 1 degree rise as described in the previous paragraph will be felt much more strongly. Rising sea levels will pose a serious threat to islands that lie just above sea level, like the Maldives and Tuvalu. Low-lying areas such as river deltas will face problems, especially if they are situated in areas that are prone to river floods and/or hurricanes. Diseases that only exist in warmer climatic zones will spread into new areas. International differences in the benefits and burdens of climate change will become an important issue on the political agenda.

It is difficult to say with certainty where the critical thresholds lie for large, complex, ecosystems like coral reefs and tropical forests. In other words, beyond which point are they no longer able to adapt to change? If an ecosystem vanishes, for example because conditions become too warm or too dry, it will no doubt be replaced by a different ecosystem. Such a transition will likely be accompanied by rapid changes, brought about in part by diseases, plagues and fires.

Based on the understanding of the consequences of climate change as described in the IPPC report of 2007, the heads of state of the 192 UN member countries agreed during the Copenhagen climate conference in December 2009 to strive together to reduce emissions as much as is needed to keep the rise in temperatures below 2 degrees. Solid agreements on what each country will have to do to achieve this target were not made. The 2 degree target that was established at Copenhagen was reconfirmed at the following 2011 summit in Cancun. In addition, because research showed that the damage suffered as a result of a 2 degree rise could be larger than previously thought, it was agreed to investigate if the 2 degree target should be tightened to 1.5 degrees.

**What if temperatures rise by 3, 4, or more degrees?**

If temperatures rise by 3 degrees until the year 2100 important ecosystems will collapse, because certain species are not able to adapt as well as others. A bird might easily fly to a new area, but the seeds of the trees that supply its food might take centuries to cover the same distance.

The tropical rainforests of the Amazon will be threatened by drought. Agriculture in subtropical and arid regions will become much more difficult. Heat and drought will drastically worsen living conditions in those areas. The melting of the Greenland and Antarctic ice sheets will probably become irreversible. The Greenland ice sheet is especially at risk. This ice sheet is a remnant of the last ice age, and is able to maintain itself because of its height. If this ice sheet starts melting, its height will be reduced. As a result, precipitation that used to fall as snow will more often fall as rain instead. This increases melting, causing the ice sheet to lose more height. At this point the system will have reached a tipping point; past this point the process reinforces itself. If this happens, a rise in sea level of several meters can no longer be prevented.

If temperatures rise by 4 degrees or more, the ’Gulf Stream’ could come to a halt, or so it was thought during the nineties. This would cause Western Europe to cool down rather than warm up. Further research has shown that the stream would not halt abruptly, but, if at all, would decrease slowly. And even if the ‘Gulf Stream’ would stagnate, it is expected that the cooling effect will not surpass the warming. North West Europe would continue to warm up even under this scenario, albeit a bit more slowly.

If temperatures rise by 3 degrees or more it will become increasingly more difficult to contain global political tensions that rise from the perceived inequality of the consequences of climate change. As long as climate change develops gradually, international cooperation might be sufficient to contain its effects. However, such a significant rise in temperatures will result in droughts and wildfires on the one hand and floods on the other, which could generate large disruptions in the affected societies, with, moreover, large refugee flows as a result.

**Tipping points: how stable is the climate system?**

Gradual changes are not the main danger when it comes to climate change. The most serious danger for both humans and ecosystems is if a tipping point is reached.

In the movie *An Inconvenient Truth*, Al Gore warns for such critical thresholds which he calls *tipping points*: a sort of no-go area. When you seesaw on a chair and release, your chair will go back to its initial position. This only works up to a certain point, however; if you pass that point you will fall backwards, irreversibly. We call this position the tipping point: a certain point in a movement or trend that is hard to determine precisely in advance, but if passed will cause irreversible harm. Regarding climate change, two questions are important. First: are these tipping points real, or are they a form of scaremongering? Secondly: is there only misery beyond these tipping points, or merely a slightly different world that is still suitable for living in?

The fact that tipping points exist in the climate systems is fairly certain. Our geological history shows plenty of abrupt changes; gradual changes seem to be more the exception than the rule. Climate scientists have been actively searching for tipping points in the climate system these past few years, for example by reconstructing climate changes from our geological past.

Figure 21 at the beginning of chapter 4 shows the progression of temperature over a period of more than 400,000 years. According to Milankovitch's theory, the transitions between colder and hotter periods should be smooth. However, measurements show that in reality this happened in fits and starts. These fits are not due to measurement errors; they are found consistently in measurements taken on different places in the earth's system: ocean floors, sea level and the ice sheets. The spikes in the temperature graph show that climate change is not a smooth, gradual process, but comes with swift and violent changes. Tipping points play an important role in this process, on smaller and larger scales. However, it is still uncertain how and when some of these tipping points are reached. It is currently thought that these tipping points might be reached when temperatures rise by 2 degrees or more, but there are scientists who say the threshold could be as low as 1.5 degrees.

What does a tipping point look like? Let us look at the well-known example of green algae in a clear lake. When phosphates and nitrogen (meaning manure or artificial fertilizers) are gradually introduced into a lake, no visible changes will occur for a good while, until the situation changes abruptly. In a short time, the clear lake transforms into a lake full of algae, which rapidly crowd out other species. In its new state the lake is again in ecological balance, but it will contain fewer different species. Once the lake reaches this state, it is almost impossible to restore it to its previous ecological richness.

Climate scientists have charted potential tipping points for several different situations and areas. One of these areas is the rainforest in South America. This forest in the Amazon region is maintained by a regional hydrological cycle, with an average precipitation of 4 millimetres daily. Part of this precipitation flows through the rivers into the ocean. Another part evaporates on the spot and remains in the air above the area. This regionally evaporated water, supplemented with vaporised ocean water carried in by air currents, comes down again as rainfall in this area. Together, these two flows of water feed the largest rainforest in the world. However, regional precipitation is changing due to global warming, as is the pattern of air currents which bring in water from the ocean. Computer simulations of climate change in this area show that this could lead to a point where the forest dries up and wildfires will occur more often. As a result of such fires, the forest will grow thinner which increases the amount of evaporation, which in turn leads to even more frequent wildfires. This process could cause the rainforest to change into a dry and barren land in a matter of decades.

These simulations and calculations show that if average precipitation drops below 3 millimetres per day, the process of drying up will start to lead a life of its own. Something similar happened to the Sahara, some 8,000 years ago. According to archaeological and geological research, this area was once rich in water and plant life. 8,000 years ago, at the very end of the last ice age and the start of the current interglacial, the area rapidly turned into a vast desert.

## POSSIBLE TIPPING POINTS IN THE CLIMATE SYSTEM

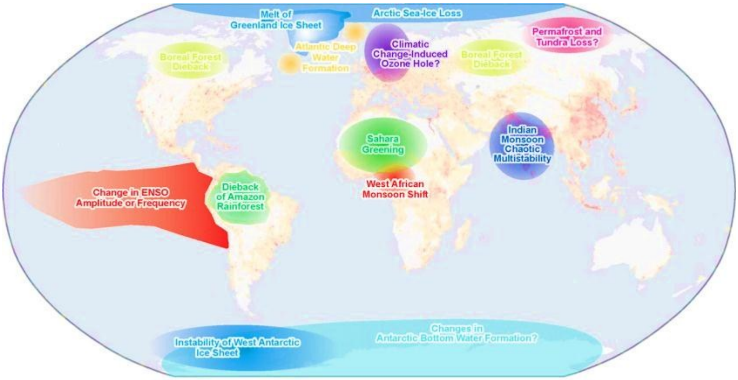



*Figure 24. Potential tipping points in the climate system which are being researched further. [Source: Lenton e.a., PNAS (2008)[29]].*

Another example of a tipping point is the accelerated melting of the Greenland and Antarctic ice sheets. This is a very recent example, because measurements show that the speed at which these masses of ice are melting has increased since 2003. There is an ongoing debate in scientific literature about whether this is a temporary acceleration caused by natural variations in climate, or if this is the start of an irreversible, self-accelerating process.

If the Greenland ice sheet melts, it will not grow back – at least not in our current climate. The world would first have to become as cold as it was during the ice age during which the ice sheet was formed. From a glance at a map, it is evident that the ice of the Greenland ice sheet stretches far south, much further than the ice sheets on the continents of North America and Asia. The ice sheet contains enough water to cause a six meter rise in sea levels if it were to melt away in its entirety. The exact rise in sea levels will differ per region, due to the gravitational effect of the mass of the ice sheet. Currently, the Greenland ice sheet pulls the ocean water around it a bit closer (because masses attract each other). If the ice sheet melts, this pull will become weaker. This could cause the level of nearby waters to actually drop slightly. The effect of reduced gravitational pull could reach as far as the North Sea. In case of a complete melting of the Greenland ice sheet, waters in this region would rise by less than six metres. Inversely, in areas which lie at a further distance from Greenland, sea levels will actually rise by more than six metres.

For the Antarctic ice sheet the same effect holds true, but in a different geographical direction. Furthermore, the amount of water held up in the Antarctic ice sheet is more than ten times the amount of that in the Greenland ice sheet. This means that if the Antarctic ice sheet were to melt, sea levels around the globe would rise over 70 metres on average. However, there is no acute danger; according to current insights, it would take many thousands of years for such a vast body of ice to melt. There are signs however, that melting of the ice sheet at West Antarctica is already contributing to the acceleration of the rise in sea levels.

**SEA LEVEL RISE DURING THE LAST WARM PERIOD**

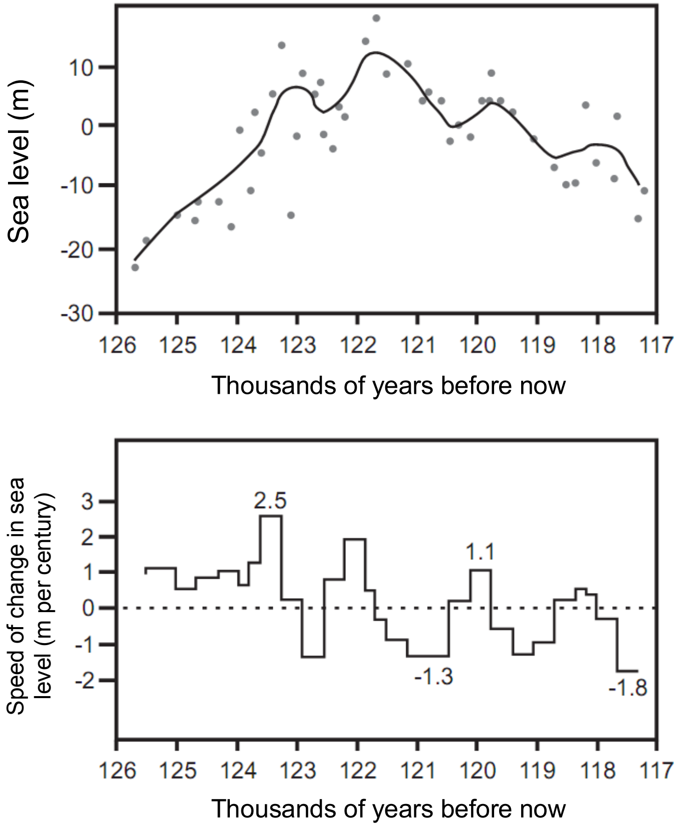



*Figure 25. During the previous interglacial (see figure 21, the penultimate peak), 120,000 to 125,000 years ago, in a situation with similar sized ice sheets as are present today, sea levels rose with peaks of 2.5 metres per century. [Source: Rohling e.a., Nature Geoscience (2008)[30]]*

During the previous interglacial, roughly 125,000 years ago, when the ice sheets were approximately the same size they are now and temperatures were some 1 to 2 degrees higher, sea levels rose with a speed of 1 to 2.5 metres per century (see figure 25). These large rises can only be explained if abrupt changes and self-reinforcing processes are included in the reconstruction of what happened. Recent research by Dutch scientist Eelco Rohling shows that sea levels fluctuate wildly during transitions from hot periods to cold periods and vice versa. These fluctuations do not happen gradually, but abruptly, varying from no change to several meters per century.

A tipping point of a different nature could occur when large amounts of greenhouse gases are released. Because of the resulting warming of the oceans, methane gas that is stored in the seabed can escape more easily. The same goes for methane gas that is stored in frozen swamps (permafrost) near the North Pole. These gases could be released rapidly when the ice melts and the soil becomes soft.

The question is whether tipping points exist that, if reached, will counteract the process of global warming. It is likely that these exist. An example is the growth of forests in currently dry areas. When more rain starts falling in a desert, vegetation will increase. Under certain circumstances, this vegetation will help retain more water in the local water cycle. This can result in a relatively swift greening of a dry area; a process that extracts large amounts of $CO_2$ from the atmosphere.

The above shows that the existence of self-reinforcing mechanisms and tipping points is important for our understanding of climate change and the influence of additional greenhouse gases. The probability of certain tipping points being reached is difficult to predict, however. James Hansen of NASA states that this probability increases strongly when the concentration of $CO_2$ is larger than 350 ppm, a level we are already well above. His personal plea is to reduce emissions drastically in order for the concentration to decrease to less than 350 ppm as quickly as possible, within a few decades.

**$CO_2$ and the acidification of the oceans**

For many years now people have been researching the effects of higher $CO_2$ levels on the growth of plants and trees. Huge greenhouses were built in which the concentration of $CO_2$ could be raised in order to verify to what extent plants could absorb it. The idea underlying this research was that if plants can store sufficient amounts of carbon, we do not have to worry that much about the additional $CO_2$ we are emitting. By now, we have gained more insight into this mechanism. Vegetation and forests can indeed store large amounts of $CO_2$, but not as much as is currently being released into the atmosphere every year. Hence, if we continue to use the same amounts of fossil fuels as we are now, the concentration of $CO_2$ in the atmosphere will continue to increase.

Over the last ten years scientists have started to take a closer look at the impact of additional $CO_2$ on marine life. For roughly 30 years it has been known that oceans absorb large quantities of the excess of atmospheric $CO_2$ (see also figure 23 in the previous chapter).

The effect this has on the biological systems is starting to manifest itself, leading to concern especially among marine biologists. The absorption of $CO_2$ increases the acidity of the

**$CO_2$ AND ACIDITY LEVELS OF THE OCEAN**

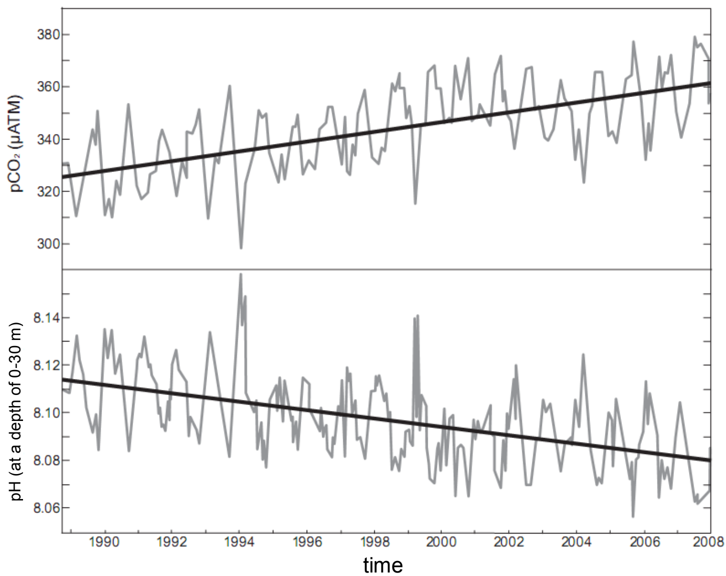



*Figure 26. The upper graph shows how the concentration of $CO_2$ in the ocean is increasing. The lower graph shows the impact of this: pH levels are dropping, which means the ocean is acidifying (a lower pH value corresponds with a more acidic ocean). Source: data from Station ALOHA on Hawaii.*[31]

ocean water. This affects animals with calcareous skeletons, like shellfish and corals, because calcium dissolves in acid. The process of acidification proceeds slowly, but in the long run it can have drastic consequences for marine life as we know it. The acidity of the oceans is therefore monitored intensively and measurements are compared with measurements taken over the last decades. The acidification of the oceans is evident. The question now is how this will evolve. Either way it is clear that the effects of additional $CO_2$ are not limited to the climate system, but also influence the quality of marine life.

**Is $CO_2$ toxic?**

In 2009 the Environmental Protection Agency in the United States put $CO_2$ on the list of toxic substances. This created the possibility to regulate industrial emissions of $CO_2$.

This classification is controversial, however. Most substances on this list have a direct effect on human and natural health. To the extent that $CO_2$ has an effect, this is much less direct. In normal concentrations, $CO_2$ is in fact essential for human and natural health. The raised concentration of $CO_2$ in the atmosphere in itself does not have any impact on people. Plants even grow better in a $CO_2$ enriched environment. Most growers increase the concentration of $CO_2$ in their greenhouses to ten times the normal level in order to stimulate growth. The $CO_2$ they use for this typically comes directly from the natural gas that is burned to heat the greenhouses.

It is not just plants in greenhouses that benefit from this $CO_2$ fertilization effect. Crops in the field also grow better when there is more $CO_2$ in the atmosphere. Furthermore, they use less water per kilogramme of crop growth. Because of the higher level of $CO_2$ it becomes easier for the plants to get a sufficient quantity, which causes the stomata of the plant to narrow a bit, which in turn leads to less evaporation of water.

However beneficial the effect of $CO_2$ may be in this regard, its impact on our climate means that a raised concentration of $CO_2$ is an undesirable disturbance for many. As such, the idea of listing $CO_2$ as a hazardous substance for the environment can be understood in light of the government's responsibilities. To regulate the reduction of emissions, legal instruments are necessary. This resembles earlier issues around acid rain and the substances that cause it, $NO_x$ (nitrous oxides) and $SO_2$ (sulphur dioxide), in which this approach to regulation was applied with success. The advantage of $NO_x$ and $SO_2$ was, however, that these substances could be filtered out by placing filters in chimneys. With $CO_2$ this is different. The volumes you would have to filter out are just as large as the volumes of the fuels burnt. This means that, compared to $NO_x$ and $SO_2$, a lot more waste has to be dealt with.

As things stand, experiments with capturing and storing $CO_2$ resulting from the burning of fossil fuels underground are taking place across the world. As mentioned, this involves enormous quantities. Where these experiments are being conducted, governments state that the underground storage of $CO_2$ poses no real threats to public health. This explanation is not accepted unequivocally, because $CO_2$, if released in large quantities, can displace the oxygen that we need to breathe. This happened once in the surroundings of Lake Nyos, a deep lake in Africa. At the bottom of this lake a large air bubble filled with $CO_2$ had formed as a result of biological and geological processes. After a sudden instability the air bubble surfaced and the $CO_2$ spread above the water and the low-lying land area around the lake. Since $CO_2$ is heavier than normal air, the air, including the oxygen it contained, was pushed upward. This explained the sudden mysterious deaths of the population living around the lake of more than a thousand people.

There are other legal instruments with which the emissions of $CO_2$ can be reduced, without placing it on the list of toxic substances, for example by introducing an energy tax based on the amount of $CO_2$ that is released when burning fossil fuels. Granting rights for the emission and trade of $CO_2$ to companies, as is happening on an EU level, is a second example.

**Natural disasters and climate change**

Natural disasters are regularly linked to global warming. This is not surprising. On average, more weather records will be broken in a world that gets hotter than in a world with a steady climate. As the world gets hotter, more water evaporates, which leads to more precipitation. When these average values increase, the probability of extreme events also increases. This leads to a bigger chance of natural disasters.

However, this does not mean that an increased occurrence of natural disasters is a proof that our climate is changing. The increase could instead be caused by a growing exposure, for example a growing population and urbanisation, bad maintenance of flood protection systems and other infrastructure, and building houses in less suitable areas.

It can also be caused by different geological phenomena. The recent flood disaster in Japan, for example, has nothing to do with climate change. In this case an earthquake, or rather a seaquake, caused a tsunami. It was already known, also in Japan, that the area that was hit was especially vulnerable to tsunamis. Traces of sediment from the seabed had been found long before on high land, where they had been deposited during previous tsunamis. The dikes simply were not high enough to counter the recent extremely powerful tsunami.

So the main question is whether weather-related disasters are linked to climate change. One can think of New Orleans and the flood catastrophe that hurricane Katrina caused in 2005, with over a hundred billion euros worth of damage. Other examples are the wildfires in Russia and the floods in Pakistan in 2010 and in Queensland (Australia) in 2011. It is impossible to say without a doubt whether or not these disasters are a consequence of climate change. These types of disaster also occur in a world without climate change. The easiest answer is therefore: "we do not know". This is not entirely true, however, because the concentration of $CO_2$ is

40 per cent higher than it was before and the earth's average temperature is up by 0.8 degrees. This rise in temperature influences the weather statistics and its extremes. The answer a climate scientist would give when asked about the connection between greenhouse gases and natural disasters would probably be as follows: 'Increased precipitation and a higher incidence of wildfires fit with what we would expect of climate change, but whether a specific flood is the result of additional greenhouse gases cannot be determined, because it might also have occurred in a world without climate change.'

Only when there are repeated heavier rainfalls in a certain area you can speak of a new trend. And only if this new trend matches the calculated consequences of climate change that were made beforehand, you can say with some certainty that there is a causal relationship between climate change and the increased rainfall. A statistical analysis of weather data over a longer period of time combined with well documented calculations of the effects of climate change are always necessary in order to be able to say something about the relationship between climate change and natural disasters.

It is all a matter of statistics, then, and exactly these statistics can help us determine to what extent the probability of an extreme weather event changes when the average temperature changes. An international team of researchers has recently shown that climate change has almost doubled the chance of floods -like those recently seen in England- compared to the first half of the twentieth century.[32] In a similar manner, the Dutch meteorological institute (KNMI) has calculated the increased probability of warm days, with temperatures above 20 degrees. The Netherlands currently has an average of 44 warm days a year, which under scenario W+ (a 4 degree rise in global average temperature) would increase to 144 warm days a year by the year 2100. The probability of a warm day increases by a factor 3 in this case. It would be fair to say that under this scenario two out of three warm days are due to climate change. See figure 27 for more expected changes in the Netherlands.

**Insurance companies and damage caused by natural disasters**

Both businesses and individuals insure themselves against damages caused by extreme weather. The insurance companies they deal with usually operate on a national level. This means that in case of a large disaster on a national scale, these companies do not have enough funds to cover all of the damages. To prevent this situation, they reinsure a large part of this risk with large international so-called *re*insurers. These large companies, like Munich Re and Swiss Re, conduct extensive research into damage from natural disasters. They keep a close eye on developments, looking not only at insured damages, but also at damages that were not insured. They notice a strong increase over the last 30 years in damage caused by natural disasters. However, it is not yet clear if this increase is caused by an increase in extreme weather, or by the higher value of goods exposed to weather extremes.

| **KNMI scenarios for 2100** | **Average over the years 1976-2005** | **G scenario** | **W+ scenario** |
|---|---|---|---|
| Global temp rise (°C) in 2100 | | +2 | +4 |
| For Netherlands 2100: | | | |
| Average summer temp. (°C) | 16.1 | 18.0 | 22.0 |
| Warm days (max. temp. ≥20°C) | 44 | 76 | 144 |
| Summer days (max. temp. ≥25°C) | 8 | 16 | 56 |
| Tropical days (max. temp. ≥30°C) | 1 | 2 | 15 |
| Average summer precipitation (mm) | 186 | 197 | 114 |
| Number of wet days in summer | | -3% | -38% |
| Average winter temp. (°C) | 3.6 | 5.4 | 8.2 |
| Frost days (min. temp. <0°C) | 41 | 22 | 6 |
| Ice days (max. temp. <0°C) | 9 | 4 | 0 |
| Average winter precipitation (mm) | 195 | 209 | 251 |
| Number of wet days in winter | | 0% | +4% |
| Annual average temp. (°C) | 9.8 | 11.7 | 15.1 |
| Average annual precipitation (mm) | 796 | 849 | 757 |
| **KNMI scenarios for 2050** | | | |
| Global temp rise (°C) in 2050 | | +1 | +2 |
| For Netherlands 2050: | | | |
| Average summer temp. (°C) | 16.1 | 17.1 | 19.1 |
| Warm days (max. temp. ≥20°C) | 44 | 58 | 96 |
| Summer days (max. temp. ≥25°C) | 8 | 11 | 25 |
| Tropical days (max. temp. ≥30°C) | 1 | 1 | 5 |
| Average summer precipitation (mm) | 186 | 192 | 149 |
| Number of wet days in summer | | +2% | -19% |
| Average winter temp. (°C) | 3.6 | 4.5 | 5.9 |
| Frost days (min. temp. <0°C) | 41 | 30 | 17 |
| Ice days (max. temp. <0°C) | 9 | 6 | 2 |
| Average winter precipitation (mm) | 195 | 202 | 223 |
| Number of wet days in winter | | 0 | +2% |
| Annual average temp. (°C) | 9.8 | 10.8 | 12.5 |
| Average annual precipitation (mm) | 796 | 823 | 776 |

*Figure 27. The left column contains average values for the period 1976-2005. The middle column contains the expected values under the KNMI's moderate 'G'-scenario. The right column shows the expected values under a more extreme*

*scenario.*

*A wet day has more than 0.1 mm of precipitation. Summer includes June, July and August. Winter includes December, January and February. The symbol ≥ means 'greater than or equal to'. [Source: KNMI 2008[33]]*

The insurance companies have done research to find out what part of the increase in damage could be due to climate change. They did this by comparing the increase in damage claims resulting from weather events with the increase in damage claims resulting from earthquakes. Presumably, increased damage due to economic developments should be equally present in both. Assuming that the likelihood of earthquakes did not change, the difference in damage growth can be attributed to climate change.

As they expected when starting their research, a large difference was found: damage from weather-related disasters grew much faster than damage caused by earthquakes. Yet, this 'evidence' has led to additional questions being raised by scientists. It is also possible that economic growth and population growth over the last few decades in areas that are vulnerable to flooding were larger than in areas that are susceptible to earthquakes. Further analysis showed that this was indeed the case. Logically, you can assume that if all other factors remain the same, climate change will lead to an increase in damage from natural disasters. Of course, those other factors do not, in fact, all remain the same. Therefore it will remain difficult to separate increases in the amount of damage as a result of climate change from increases due to continuing economic development, and changes in average vulnerability.

**Liability for climate change**

The degree of certainty that is desired in decisions about climate change increases with the size of what is at stake. For a company that thrives on fossil fuels, or for a farmer with methane-producing cows, there is a lot at stake. They will want to be absolutely certain about the effectiveness of proposed measures to combat climate change. Only when change is inevitable, and it is clear that the proposed measures will actually be effective, will they be prepared to take action.

The stakes are also high for people who live below sea level: a small change in the strength of hurricanes and storm surges could have disastrous consequences for them. The risk of an unstoppable rise in sea levels is another reason for low-lying territories to plead for preventive measures. They will prefer to work based on the precautionary principle. This principle states that if there is a probability that human action could cause large, irreversible effects, this action should be halted, even if we do not know for certain what the effects will be.

Countries that respect the principles of international law will have to use these principles as a touchstone for the consequences of their greenhouse gas emissions.[34] International treaties dictate that it is not allowed to undertake activities that are known to cause damage to other countries. With climate change, the question is to what extent the consequences can be 'known'. At present, the effects of climate change are fairly small when related to natural variations. But as time goes by, the impact of certain phenomena will become larger and more clearly distinguishable.

For example, the aforementioned island state of Tuvalu has considered suing Australia and the United States at the International Court of Justice in The Hague. According to Tuvalu these countries cause damage to the island because their use of fossil fuels accelerates the rise of sea levels. Tuvalu invokes the IPCC reports in which this causality is shown. A court case like this currently does not stand much of a chance; the changes are too small and liability is hard to prove. The time series of changes in the yearly average water levels around the island show larger variations than the rise due to climate change measured so far. In statistical terms: the signal is not yet clear, because the noise is larger than the signal. But will it stay this way? Studies by the World Bank estimate the damage that would occur in developing countries if the world heats up by 2 degrees at around 70 to 100 billion dollars annually by the year 2050.[35]

# 6

## *Can we not simply adjust to climate change?*

People have an enormous ability to adapt to their environment. They live everywhere from the arctic to the jungle, from the desert to the wet deltas of the great rivers. Native American tribes in the Amazon are thought to have migrated all the way from hot, arid East Africa via the sub-Arctic Bering Strait to the tropical rainforest. The Netherlands was made habitable by the construction of dikes and the continuous drainage of water.

Despite the ongoing debate regarding the uncertainties of climate change, major firms and agencies such as the Dutch “Rijkswaterstaat” (the department of Public Works and Water Management) and the US Army Corps of Engineers are already taking climate change into account, especially with the construction of hydraulic engineering works. It is not necessary to alter existing structures right now. There is still time for that: if sea levels were to rise by one meter during the next one hundred years, that would mean an annual rise of no more than one centimetre. This may be five times as fast as it used to be, but if we keep an eye on the yearly rise in sea levels and make changes to the waterworks where needed, we will manage for the foreseeable future.

The question that arises is whether perhaps it would be better to focus more on adapting to climate change, and less on reducing emissions. To answer this question, we look at The Netherlands as an example. There are three reasons why a focus on adaptations in favour of reductions might create trouble. The first reason is that the Netherlands is a country with an energy intensive economy, and as such produces a lot of greenhouse gas emissions. This means that they have to take into account the damage they cause elsewhere in the world. If, in the future, it is decided to distribute the burden of climate change according to historical emissions, this would spell trouble for them. The second reason is that in the long run, enormous damage could be done to the Netherlands especially. There is a real threat of the sea level rising by a few metres, and the country's low-lying position renders it more vulnerable to the consequences of such a rise than many other countries. This also means that flood protection measures will be much more expensive, and the same goes for the adaptation of the harbours and the draining of water when rainfall turns heavier. Lastly, if climate change starts causing increased crop failure and floods in other parts of the world, the effects in terms of political conflict and possible refugee flows will be felt the world over.

**Emission reduction or adaptation? An economic consideration**

For the past thirty years, various economists have explored the best course of action: reducing emissions, or adapting to climate change. Macroeconomists especially have set the tone in this debate. They consider the problem on a global scale, comparing the costs of investing in things like alternative energy sources with the long-term benefits, i.e.

reduced damage from climate change. These economists believe that an emphasis on emission reduction is preferable if the benefits in terms of reduced damage and casualties are greater than the costs. These costs consist of the amount of money needed to invest now, plus the loss of interest you could otherwise have received over the invested funds.

Two factors prove to be very important to the result of these calculations. The first one is the discount rate used in the calculations, and the second one is the estimated scope of future climate damage.

The discount rate represents the value we place on something the next generations will inherit, in this case a reduction in climate damage. If we choose to use a high discount rate, say 5 per cent, we assume that the economy will continue to grow. In essence, we are assuming that future generations, even in places like Bangladesh, will be wealthy and technologically advanced enough to take preventive measures to curtail climate damage. Choosing a low discount rate, say 2 per cent, means we prioritize providing the bare necessities of life (such as a relatively stable climate) for future generations without any great risks. The choice for a low discount rate is like the choice for good stewardship; the economists who base their calculations on a high discount rate implicitly take for granted that the next generations will be richer than we are, and that money solves all (climate) problems.

There are numerous subjective elements to estimating future damages as well. These damages depend on spatial planning and the decisions that will be taken in that area over the next decades, for example on the expansion of cities in low-lying areas, or the development of ski areas. In order to be able to make an analysis, scientists use different scenarios in their calculations.

The first economists to make these kinds of calculations were the American Bill Nordhaus and later the Dutchman Richard Tol, who followed in his footsteps. In their calculations, they used a fairly high discount rate, as is usual in investment banking; they assumed a value of around 5 percent. With regard to climate damage, they assumed a gradual change in climate. Abrupt changes were not included in their calculations, partly because it is not really possible to estimate these and translate them into costs. Additionally, they only calculated material damages, leaving aside potential cultural and ecological damage.

In their calculations, Nordhaus and Tol came to the conclusion that climate damage over the next 50 to 100 years will be less significant than the cost of investing in emission reduction plus the loss of interest. According to them, this meant that we would do best to just wait, and that it was not worth the cost of investing in reducing greenhouse gas emissions at present.

Crucial to this outcome is the long period of time between current emissions and future climate damage (in about thirty to a hundred years). Potential climate damage occurring fifty or more years from now barely counts anymore in these calculations because of the discount rate used. After all, five per cent interest over fifty years results in such a large figure that more climate damage could be paid than anyone could imagine.

However, Nordhaus and Tol were not the only ones who concerned themselves with this question. Economists who delved into the subject after them, such as Nicolas Stern in 2006, used much higher estimates for climate damage than Nordhaus and Tol. At the same time, they chose to use a lower discount rate. They did this on the basis that the value of a relatively stable climate for future generations should not be compared directly to short-term investments into current needs. Stern's calculations lead to the conclusion that significant investment in emission reductions is the most desirable scenario.

In 2008, Dutch economist Jeroen van den Bergh took an even broader look at the costs and benefits of a transition from fossil fuels to sustainable energy. He included the cost to society of the current energy supply in his consideration; for example, health care expenses as a result of air pollution. Like Stern, he based his calculations on a low discount rate. His conclusion was that the type of model that Nordhaus and Tol used was inadequate for the question they used it on. Van den Bergh's approach leads to the conclusion that emission reduction through a transition to other energy sources is even more desirable than Stern indicated, and therefore emerges even stronger as a priority.

None of the abovementioned economists included the possibility of tipping points, abrupt and irreversible climate changes, in their calculations. This would be very hard to do, because insights into when this phenomenon takes place and what will happen after are insufficient in order to incorporate them into economic analysis. Since the question of whether to invest in emission reductions or adapt to climate change involves both current emissions and hardly quantifiable damage over the next thirty to a hundred years, no perfect economic models exist which can help us make a realistic assessment.

Furthermore, the choice between these two alternatives is

**AVERAGE YEARLY TEMPERATURE OVER THE PAST 100 YEARS**

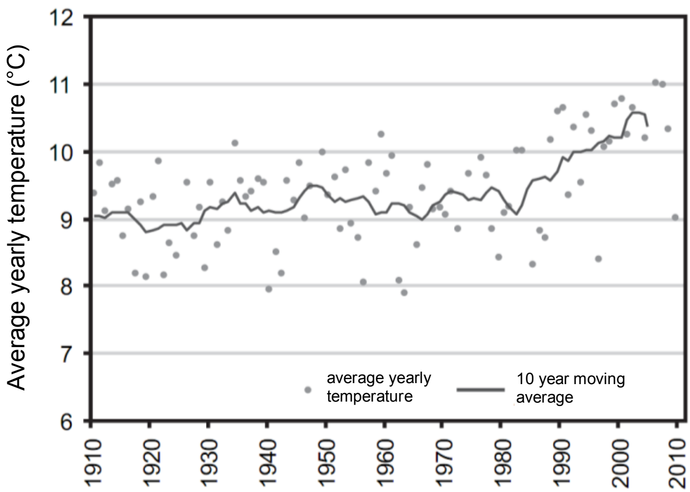



*Figure 28. The average temperature in the Netherlands between 1910 and 2010, as measured by the KNMI. The dots represent a yearly average; the dark line is a ten year moving average. [Source: KNMI[36]]*

not made solely on the basis of cost benefit analysis; it also involves ethical and moral considerations. The question is to what extent we can still condone the unbridled use of fossil fuels, when we know that the effects thereof can cause extensive damage for other countries and future generations.

Moreover, the amount of effort we decide to put into reducing emissions largely determines what adaptations will need to be made. At the same time, adapting to climate change is also necessary, because it is already ongoing and emissions of greenhouse gases are likely to continue for at least a few decades.

**PRECIPITATION AT WEATHER STATION DE BILT OVER THE PAST 100 YEARS**

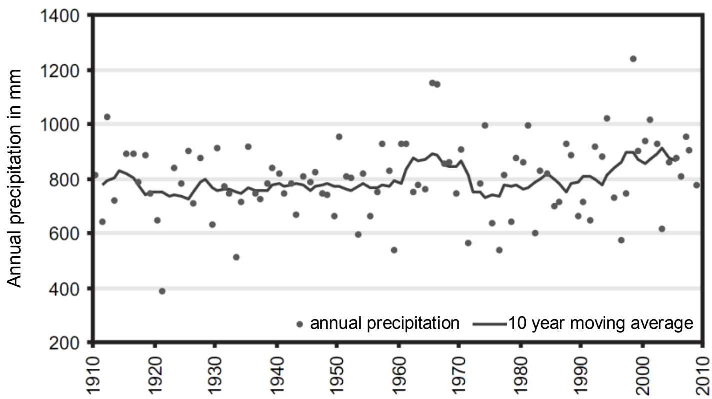



*Figure 29. Precipitation at weather station De Bilt in the Netherlands between 1910 and 2010. The dark line is a ten year moving average. [Source: KNMI[37]]*

**CHANGES IN HABITATION OF HEAT-LOVING AND COLD-LOVING SPECIES**

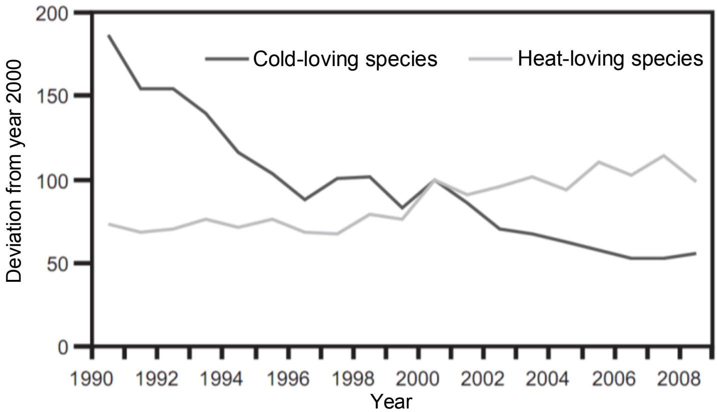



*Figure 30. Since 1990 the number of cold-loving species (such as the godwit, the Short-eared owl and the Cranberry Blue) in the Netherlands has been declining, while the number of heat-loving species (such as the oystercatcher, the starling, the tree frog and the Map) has increased. [Source: Compendium voor de Leefomgeving[38]]*

**What would adapting to climate change involve?**

During the last twenty years, the first consequences of climate change have become clearer. The earth's average temperature is approximately 0.8 degrees higher than it was a hundred years ago; the majority of this increase in temperature took place during the last 40 years. In the Netherlands, which we are still using as an example, a rise in the average yearly temperature as well as an –albeit limited- increase in total annual rainfall have been measured; see figure 28 and figure 29.

Growing season has lengthened. Cities grow warmer. More and more plants and birds are being spotted which used to only live in Southern European countries, while an increasing number of cold-loving species are declining in number – see figure 30.

In recent years, a lot of research has been done into the question of how we can best prepare for climate change. Nowadays, many plans for investments in the spatial planning sector are being tested on how climate proof they are. If the damage attendant on a plan or building in case of further climate change is found to be too large, ways to amend this plan are examined. The criterion used is that the extra investments need to weigh up to the benefits of reduced climate damage in the future. As we saw before, the results of these calculations are highly dependent on the assumed discount rate. Because the future is always uncertain, other lines of reasoning are used as well. One of these is the so-called *no regrets strategy*. The no regrets strategy is based on the following argument: if an adaptation has any merit at all, even if our climate does not change further, it is wise to invest in that adaptation now. The return may not be optimal, but you will not regret your investment no matter what happens. The construction of a dike that is slightly sturdier than would be strictly necessary in order to adhere to current safety standards, for example, can be viewed as a no regrets measure, since it already offers added safety and therefore has some benefit. Planting more trees in the city in order to provide some shade during hot summers is a no regrets measure, too; after all, people will benefit from it whether it gets hotter or not.

Another strategy is the precautionary approach. This approach is used mainly in situations where there is a lot at stake. The probability of damage occurring is not entirely clear, but the possible extent of that damage is so great that you are willing to avoid it at any cost. Taking out fire insurance is an example of such a precautionary measure.

An example related to climate change is the small added investment that was made in the construction of the Tweede Maasvlakte, an addition to Rotterdam Harbour in the Netherlands. During its construction, the pipelines running on and parallel to the quays were laid in such a way that no costly adaptations will be needed if the sea level starts rising faster in the future. Another example of such a precaution is the storm surge barrier near Rotterdam, the Maeslantkering, which was built on a slightly higher level because future adaptation would be a very costly project. If the sea level does not rise as expected, these measures, unlike the no regrets measures, will have no economic return. These kinds of considerations also come into play with new buildings. It usually costs little extra money to take into the account the possibility of hotter summers when planning and installing a climate control system. If it needs to be installed in ten years after a couple of heat waves, it will be much more expensive. According to the Dutch meteorological institute (KNMI), we will also see more heavy rain because of global warming. Therefore, it is better to choose a larger size sewer pipe when replacing old ones; it can prevent a lot of flood damage and hence save money.

**Climate change and nature**

The benefits of investing in the built environment can be measured reasonably well, but the effects of climate change on nature are harder to pin down. It is certain that global warming will create a breeding ground for new diseases and plagues. A few examples of this can already be noticed, such as the caterpillars of the Oak Processionary moth advancing northwards. Another example is the insects (midges) that cause Bluetongue disease in sheep and cows. Due to warmer winters, they can perpetuate and propagate themselves better than before.

The only way to allow for climate change in the management of natural areas is to provide flexibility as well as connections. Existing species will try to adapt to changes through natural selection, which means that those specimens that are better equipped to deal with the changes will be more successful in reproduction. Furthermore, migrating along with the climate zones can be an alternative. The latter can be fostered by connecting different natural areas. This seems simple, but in practice can be troublesome. The existing natural areas in many countries are surrounded by what amount to insurmountable barriers for plants and wildlife; roads, buildings and in many cases intensive agriculture, which means tough choices need to be made by those in charge. What makes these choices even harder is the fact that there are downsides to these connections as well: they facilitate the spread of diseases and plagues.

Inevitably, climate change will cause certain species of plants and animals to disappear forever, while others will get a chance to flourish. However, if climate change proceeds as predicted, this process will move in fits and starts. When a certain species does not make it, the lower species like weeds will be the first to fill in the open spaces. Because of the hard to predict but potentially far-reaching influence of climate change on nature, ecologists generally plead for a stronger restriction on greenhouse gases than meteorologists, engineers and economists.

**A new Deltaplan**

It is possible to defend a country like the Netherlands against a relatively swift change in climate by strengthening dikes and dunes every twenty or forty years. The question is, will these measures will be sufficient in the long term? After all, with global warming and melting icecaps, the sea level will continue to rise. As a consequence, the wall of water threatening the country will get higher and higher. In light of this, does it even make sense to keep living and working in the western part of the Netherlands? Or would it be better to invest in a shift to higher ground? In order to answer questions of this nature, the Tweede Deltacommissie (the second delta commission) was established at the end of 2007, under the leadership of former minister of agriculture Cees Veerman. The commission did not solely concern itself with climate change. It was also asked to investigate how maintenance of the country’s flood protection had run so far behind: an inspection of water levees in 2006 showed that over 25 percent no longer lived up to the standards imposed by the first delta commission that was established directly after the disastrous floods in the province of Zeeland in 1953 (known nationally as the Watersnoodramp). For another percentage of the levees the level of safety was found to be unclear.

The second delta commission was asked to advice the government on the best ways to make the Netherlands climate proof for the long term. To be more precise: protected against floods, and at the same time an attractive place to live, work, recreate and invest.

The commission wanted to extend its investigation beyond the average scenarios stipulated by the national meteorological institute KNMI. These KNMI scenarios reflected the most likely development of climate change, but the commission was also interested to see what the consequences would be for the country if the upper limits of the IPCC’s predictions, a temperature rise of 4 to 6 degrees, were to become reality. The Netherlands was not the only area with an interest in these scenarios. California’s Silicon Valley, the water levees in the Thames in England and the storm surge barriers in Venice are examples were these upper boundaries are also taken into account.

An investigation into the upper boundaries of sea level rise proved to be difficult. Especially so because the unexpected acceleration of the melting of icecaps in Greenland and Antarctica proved earlier calculations inaccurate.

The worlds most experienced scientists in this area were flown in on the commission's request in an attempt to make as accurate an analysis as possible of the upper limits for sea level rise by the year 2100 and the year 2200[1]. The results of these calculations and studies are presented together with earlier predictions of the KNMI in figure 31. The international team of scientists found upper limits for the year 2100 of 0.6 to 1.2 metres of sea level rise and of 2 to 4 metres for the year 2200. In September 2008, the commission presented its advice. The foreword characterises the commission's advice on how to deal with climate change:

'*… the threat is not immediate, but the task is urgent. There is no reason to panic, but we have to be concerned about the future […]. It is essential to realize that the challenges facing the Netherlands in the coming century are not primarily characterized by threat, but can also offer a new perspective. Adapting our country to the consequences of climate change creates new possibilities, and working with water affords unique opportunities […].*'

The commission's conclusion was that adequate investments and timely adaptation of flood protection works and water management will allow the Dutch to keep the Netherlands

[1] These upper limit scenarios were constructed at the request of the delta commission by an international team of experts headed by the author of this book. The results were published by the KNMI and later by the scientific journal *Climatic Change* (see also note 40). The author was repeatedly consulted by, but was not a part of, the second delta commission.

**SCENARIOS FOR SEA LEVEL RISE**

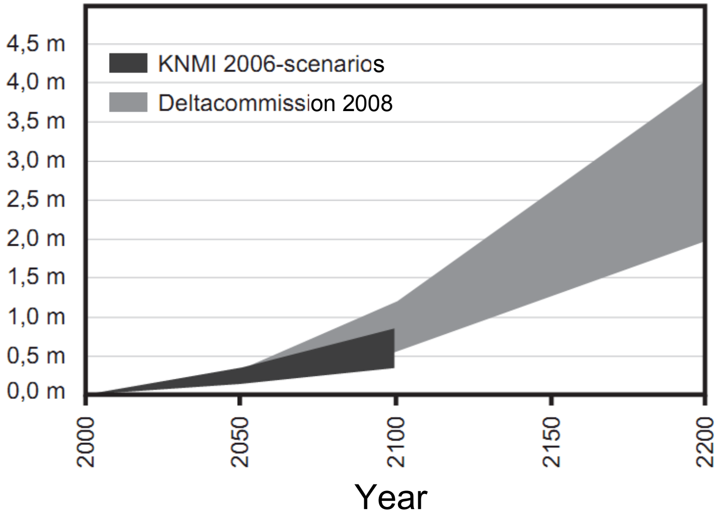



*Figure 31. Scenarios for the upper limits of sea level rise in 2100 and 2200. KNMI scenarios up to 2100 and the upper limit scenarios of the second delta commission up to 2200. [Source: Delta commission (2008)[39]]*

liveable, even if the sea level rises by 2 to 4 meters in the next two hundred years.

The media and the political establishment received the new scenarios with scepticism, because they were higher than the IPCC scenarios and the previous estimates made by the KNMI. What the critics overlooked was that these new estimates were worst case scenarios. When planning the coastal protection measures, it is important to take worst case scenarios into account in the final decisions on spatial planning and protective measures, especially as these require large investments with an - intended - long lifespan. Other countries have subsequently conducted similar investigations. It turns out that the UK, for example, assumes an even higher sea level rise in a worst case scenario: up to 2 metres by the year 2100.

**Solutions for the Netherlands if the sea level were to rise sharply**

The Netherlands has three options to respond to a strong rise in sea level. First, there is the forward approach: raising a large dike in the North Sea that prevents a storm surge from reaching the coast. This will create a border lake that can serve as a deposit for high river discharges – see figure 32. This solution, while technically possible, brings several risks with it: the freshwater lake that will be created is ecologically fragile, the ports of the Netherlands will no longer be directly accessible and the initial costs are very high. As such, it will not be easy to find the necessary financial means for this large scale solution.

## THE FORWARD APPROACH: A DIKE IN THE NORTH SEA

*Figure 32. The forward approach: building a dike some 30 kilometres off the coast to protect against floods from the sea. [Source: Vellinga (2008)[40]]*

The second approach is to retreat to the east. New investments would be directed primarily towards higher situated areas, which would form the new focal point for habitation and construction. If the sea level rises drastically, the western part of the Netherlands could eventually be abandoned altogether. The cost of retreating from the lower lying areas could turn out to be enormous, however, even if taken over a period of a hundred years. Staying and working in the lower lying parts of the Netherlands makes enough money to fund higher and stronger dikes.

After comparing different options, the delta commission advised to protect the country within the existing contours. This approach will also require investments, but it is far less costly than the previously discussed options. If the river estuaries are kept open, the so-called "open coastline", this option is also attractive from an ecological standpoint.

Figure 33 shows two potential variants to this approach: an open coastline or a closed one. The advantage of the closed coast is that the coastline is short, while the water of the North Sea is kept out completely. The disadvantage is that the rivers can no longer flow freely into the sea. While this keeps the sea at bay, the country will still be vulnerable to high water levels in the rivers if the water cannot be released into the sea during a storm surge. The probability of this happening may not be very high, but it increases as the sea level rises and the maximum river discharge gets higher. Another disadvantage is the separation of freshwater and saltwater. Experiences with the IJsselmeer and the estuaries in Zeeland have taught us that a strict separation of saltwater and freshwater has severe negative consequences for the local environment. In these cases, water that turned fresh by being separated became overgrown with algae, which made recreation and mussel cultivation impossible. A section of the estuaries, which turned freshwater as a result of the Deltaplan (the plan drafted by the first delta commission), is now being reopened for this reason.

**CLOSED OR OPEN COASTLINE**

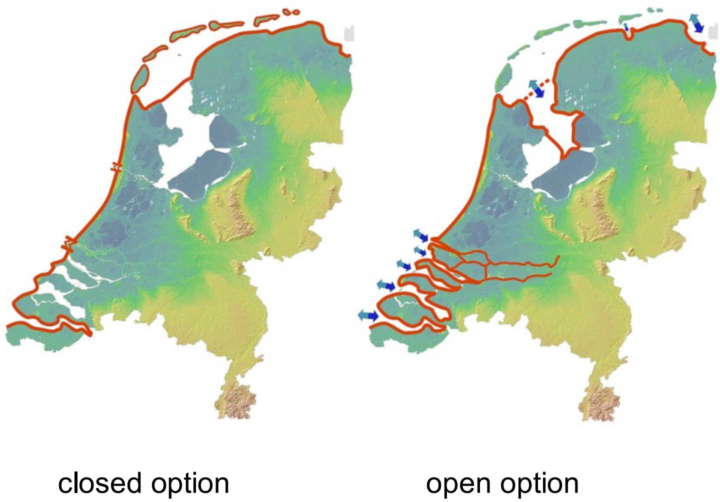



*Figure 33. Protecting the country within its existing borders, with a closed coastline (left) or an open coastline (right). Zeeland and the IJsselmeer would have a (semi) open connection with the sea in this last option. [Source: Vellinga (2008)*[41]

If the coastline is kept open, the North Sea is allowed to enter further land inwards. This necessitates strengthening the dikes. The length over which this strengthening has to be done depends on the choice that is made: will the estuaries remain open during storm surges, as is the case for the rivers Westerschelde and Eems, or will they be closed, as is the case for the Oosterschelde and the Nieuwe Waterweg in Rotterdam?

The second delta commission advises the option in which the estuaries are kept open as much as possible. As a result, the effects of a rising sea level will perpetuate further upstream. This would only start happening some fifty to a hundred years from now, so there is time to make the necessary adaptations to agriculture and water supply systems. This option does require stronger dikes, over a greater length, along the estuaries and the rivers. Will the dikes need continuous raising, or are there other options?

One solution that is receiving more and more attention is to build broad, unbreakable dikes. These are dikes that will not break, even if the water level rises above the top. In case of extremely high water levels, the worst that will happen with this type of dike is a temporary flooding during the short period that the storm rages at sea or the rivers are extremely high. A temporary overflowing of the dikes like this will let in significantly less water than a dike breach. When a narrow dike breaks through, the water can easily come all the way up to the roof, while the broad, unbreakable dike’s temporary overflowing will keep below the windowsill. There will still be some damage, but significantly less than there would be if a dike breaks. And nobody will drown. A flood will have an effect comparable to a heavy downpour: a nuisance, but not a disaster.

An unbreakable dike would be roughly twice as broad as a traditional one, assuming it is build according to the traditional design with natural materials and gentle slopes. Its increased broadness can be utilized by using the surface for urban functions or for recreational purposes, for example by building cycling paths. While the current narrow dikes do usually allow for car traffic, they leave little space for cyclists and hikers. Figure 34 shows a sketch of a broad dike and how it could be utilized.

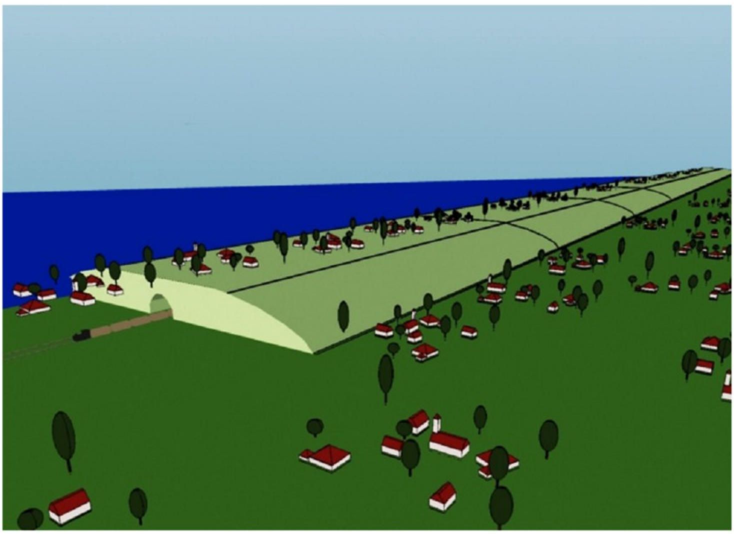


*Figure 34. The 'broad dike': multifunctional and unbreakable. [Source: Vellinga (2008)[42]}*

**What would it cost to make the Netherlands climate proof?**

Earlier in this book it was noted that the World Bank estimates the cost of adaptation in developing countries to be in the area of 70 to 100 billion dollars annually. For the Netherlands, the costs are estimated at one or two billion euros a year, starting from 2020. The exact amount will depend on the speed of climate change and the timing of investments. Timely measures will make adaptation cheaper, because they can be incorporated into the usual maintenance cycles and renewal programs, and the costs can be borne by the traditional functions such as water management, coastal defence, urban development, recreation and development of natural areas.

Research performed by the research organisation Kennis voor Klimaat (Knowledge for Climate) shows that in the period from 1990 to 2010, more than a hundred projects were developed in the area of spatial planning and housing in which the effects of climate change were considered.[43] Taking climate change into account implies looking at a larger timespan and a broader spatial orientation. This requires a large amount of creativity and involvement from stakeholders. Research shows that in most cases this approach led to innovative results, which were not necessarily more expensive and which garnered appreciation and support from stakeholders. Figure 35 shows several examples of such projects in Rotterdam.

*Figure 35. Several examples of possible adaptations to climate change. The top three images display a playing ground that offers different possibilities under different weather conditions (and the accompanying water levels), the bottom image shows a green roof. [Source: Rotterdam Climate Proof[44]]*

As this chapter has shown, it is possible to adapt to climate change to a certain degree, in the Netherlands as well as elsewhere. This does not mean, however, that we can forget about tackling the causes of this problem: the greenhouse gases that are emitted as a result of the use of fossil fuels, and through the way we farm and supply ourselves with food.

# 7

## *Switching to alternative sources of energy may be too expensive.*

Supplies of fossil fuels are finite. Hence, prices of this source of energy will rise as long as the global economy keeps growing. This rise in prices also makes it possible to continue exploring and exploiting additional fossil fuel sources; scarcity and subsequent higher prices stimulate the search for additional sources. As such, there will not be an absolute scarcity in fossil fuels during the next few hundreds of years. By putting new exploitation technologies to use, enough natural gas can be won worldwide from the pores of shale and rhinestone for the next hundreds of years (shale gas). The exploitation costs of these reserves are higher than the cost of extracting gas from a gas bubble, but exploitation has become commercially feasible. Crude oil seems to have become scarcer, but with higher prices it becomes economically attractive to pump $CO_2$ into the old oil fields in order to extract an additional 30 percent of oil. Furthermore, there are huge reserves of tar sands from which oil can be produced, albeit with serious ecological implications for the landscape and local quality of the environment. Current supplies of charcoal will last us for hundreds of years to come.

Fossil fuel reserves are plentiful, but extracting them will become increasingly expensive.

The use of fossil fuels is deeply anchored in western society. This holds true to some degree for the entire world. That there are large differences in energy consumption across countries can be seen in figure 36. There are billions of people across the globe who aspire to the Western, energy intensive lifestyle.

**AVERAGE ENERGY CONSUMPTION PER CAPITA**

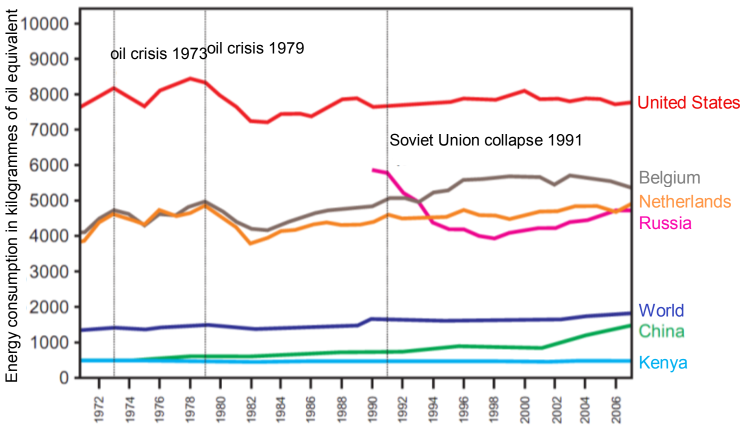



*Figure 36. Annual energy consumption per capita in different countries along with the world average. A tonne of oil equivalent equals the amount of energy that would be released when burning a tonne of crude oil. [Source: World Bank (2010)[45]]*

Fossil fuels are in essence a compact form of solar energy, stored in plants that were pressed together under high pressure to form charcoal, oil and gas. Because of this, fossil fuels are hard to beat when it comes to energy density. This makes them easy to transport and store, and ideal for use in road and air transport.

However, next to climate change there are other major downsides to using fossil fuels. Energy producing countries can use our dependency on fossil fuels to keep us in a stranglehold. We try to prevent this by making international treaties, and if that fails, we send in the troops. This is both costly and risky. Another disadvantage is that the use of fossil fuels causes air pollution. Air pollution caused by automotive transport in cities especially damages the public health and causes premature deaths across the globe, despite numerous kinds of filters.

But is an affluent economy without this air pollution and without $CO_2$ emissions even feasible? It often turns out that people's views on climate change depend strongly on their answer to this question. Initially, alternative sources of energy seemed to be very expensive. However, insights into the costs of alternative energy sources are changing rapidly. Over the last few years, many technical and economic studies have been done into the possibilities and costs of switching to a (more) climate neutral energy supply system. This includes energy efficiency, various forms of sustainable energy, nuclear energy and the possibility of capturing and storing the carbon that is released from power plants. These studies show that there are many technologies available that would allow us to gradually move on without fossil fuels. However, a transition like this would take a lot of time: we are talking thirty to fifty years, easily. On top of that, large investments would be required. The costs of switching to a climate neutral economy by the year 2050 would raise the price of energy by an estimated 10 to 30 percent, depending on how effectively different nations will cooperate on an international level.

This is by no means a small increase of the base price of energy, but it is significantly smaller than the price changes we have seen over the last twenty years. Several studies, including those done by renowned institutes like the International Energy Agency in Paris, large energy companies like the German RWE and large consultancy firms like McKinsey, all conclude that the transition can be made within 40 years without any noteworthy effects on the overall economy. A very elaborate study by McKinsey, published in 2010, shows that Europe would face an increase in the cost of energy of around fifteen percent. While the costs would initially be higher than the benefits because of the required investments, the benefits soon start to outweigh the costs when taking into account all social costs and benefits. This includes four types of benefits: reduced reliance on other countries for energy supplies (increased energy security), cleaner air and associated health benefits in cities, less climate change and beneficial effects of countries investing in their own economies.

**Nuclear energy and underground storage of $CO_2$**

One way to reduce emissions is by storing $CO_2$. It is technically possible to store $CO_2$ in old gas fields or in the pores of other underground rock formations. This is already being done in several places across the world. For example, $CO_2$ has been used to increase the pressure in oil and gas fields in order to pump out the last 30 percent. The $CO_2$ remains behind in the depths, which means less of it ends up in the atmosphere. It does, however, cost energy to capture and compress $CO_2$ and to get it to the right place through a network of pipes. It also requires a sizeable investment to put the necessary infrastructure in place. When this technology is applied in coal-fired plants it causes the cost of electricity generation to go up by 30 to 40 percent.

This means that, if this technology is applied, energy intensive industries will have to spend roughly 40 percent more on energy. For smaller businesses and individuals the price rise would be limited to roughly 10 to 20 percent, because for this group the cost of transport and existing taxes already make up more than half of their energy bill.

In summary, the costs of storing $CO_2$ are significant, but not insurmountable. For energy intensive businesses that compete internationally, it is important that businesses in other countries face similar cost hikes, in order to prevent unfair competition.

As such, $CO_2$ storage can be a solution, but not all locations are suitable for it. As mentioned, a massive leakage of $CO_2$ from the storage could be life-threatening for people in the immediate vicinity. Even though the probability of such an accident happening is very small, the potential consequences give rise to public opposition against this form of $CO_2$ management in densely populated areas. The risks associated with $CO_2$ leakage can be partly mitigated by storing the $CO_2$ under the seafloor; a potential release would not pose a threat to people. When applied to power stations that run on biomass, $CO_2$ storage even has a beneficial effect (biomass includes both animal and plant materials, like palm oil, rapeseed oil, wood, waste wood, roadside grass, agricultural residues, fertilizer, algae, abattoir waste etc.). In this case, energy is produced while at the same time extracting $CO_2$ from the atmosphere. This goes as follows: trees and plants absorb $CO_2$ from the atmosphere when growing. Next, these trees are burned in a power plant. The end product of this process is energy, while the $CO_2$ stored in the trees is put underground. In this way, the power plant becomes a $CO_2$ absorber. This only works under the condition that new plants and trees are planted to replace the ones that were used for generating energy. These new plants and trees then go through the same process. Under these conditions, energy is produced in a way that is not just climate neutral, it is climate positive.

Nuclear energy is another alternative if we want to switch to a more climate neutral energy supply system. Although the actual costs of this form of energy generation are a continuous matter of debate, it is likely to be cheaper than traditional electricity generation combined with $CO_2$ storage. However, just as in the case of $CO_2$ storage, there is public resistance against this form of energy generation. This resistance revolves around three risks: the possibility of accidents like the ones which happened in Chernobyl and more recently in Japan; the possibility of using the spent fuel for military purposes and the risk of nuclear waste being released into the environment. The recent accident in Japan (March 2011) demonstrates that the risks are greater than previously assumed. In actuality, the number of people that will fall ill will probably not be very large. However, the idea that harmful radioactive radiation spreads into the surrounding area and could make its way into the food chain causes a lot of unrest. To prevent accidents like these from happening, further measures will need to be taken, which in turn means that the price of nuclear energy will increase. Additionally, the potential military application of this technology remains and issue. It is not without reason that Iran is committed to building nuclear power plants. In closing: while nuclear energy is becoming more expensive (due in part to extra safety measures after the incident in Japan), sustainable energy is becoming cheaper. As a result, nuclear energy will probably play no more than a modest role in a climate neutral energy supply system, even if the global effort for $CO_2$ reductions is intensified.

**Sustainable energy and increasing efficiency**

Sustainable energy sources are another topic of public discussion. These sources require space, produce high levels of noise or compete with food sources and natural areas. However, the fact that these sources are virtually infinite and produce little to no greenhouse gases makes them interesting nonetheless. The sun, hydropower, wind, biomass, and geothermal energy are all sustainable energy sources.

In recent years a lot of research has been done into the feasibility of replacing fossil fuels with renewable sources of energy. The results show that much more is possible than was thought until recently. An elaborate study in which several large European energy companies participated shows that a) maintaining the traditional energy supply system with high $CO_2$ emissions, or b) switching to an energy supply system that combines nuclear energy and $CO_2$ storage, or c) switching fully to renewable sources of energy would all have approximately the same effect on the European economy. The costs of a climate neutral energy supply in Europe are mainly dictated by the timing of investments and the degree of cooperation between EU countries. [46] A substantial increase in the efficiency with which we use our energy plays an important part in all these scenarios.

*Increasing the efficiency of energy usage*

Time and again it turns out that saving energy, or in other words increasing the efficiency of energy usage, is both technically and economically the most attractive way of reducing greenhouse gas emissions. However, there are many missed opportunities in this area. A comparison between countries reveals that high energy prices (or high prices for $CO_2$ emission rights or a high tax on $CO_2$) are the main driving force for both companies and individuals to invest in energy efficiency. However, making these kinds of demands turns out to be politically difficult for governments.

For existing buildings, for example, voluntary measures have been promoted, but this has yielded little result up until now. This is not unexpected: even if calculations show that an energy saving measure is cost effective, inhabitants of a building will still wonder whether they can recover the initial costs before they move to a new house (for example).

It is easier to set standards for consumer goods like cars, washing machines, refrigerators and computers. That is why this is what happens in practice, usually at European Union level. The clearest example is the standard set for $CO_2$ emissions from passenger cars. In response to this standard, all car manufacturers suddenly started bringing cars to the market which are much more fuel efficient.

*Wind energy*

Modern wind energy has seen a strong development during the last decade. Wind turbines on land ('onshore' turbines) can now produce electricity at prices that can compete with electricity from fossil sources. Wind energy at sea ('offshore' turbines) is more expensive, but the construction of more and larger turbines is lowering the cost per kilowatt there as well. If current trends continue, offshore wind will be able to compete with fossil electricity by the year 2025.

The disadvantage of wind energy is that it requires a backup source of energy for when the wind is not blowing. Gas-fired plants are best suited for this, because they can be switched off and on rapidly. Nuclear plants and coal-fired plants have a much longer start-up time and therefore do not combine well with an increase of solar and wind energy. As such, proponents of renewable energy tend to favour gas-fired plants and oppose nuclear and coal-fired plants.

The Netherlands, for example, could theoretically draw all its electricity from offshore wind turbines in the North Sea, though it would require strong connections with different energy parks throughout Europe in order to bridge times with little wind. These other parks might include hydropower from Norway, solar parks in Spain and Dutch (bio) gas installations. Development of wind energy also has the potential to create jobs, more so than nuclear energy for example, and offshore wind can benefit the economy of countries with a developed maritime engineering sector.

*Solar energy*

Solar energy is quickly becoming cheaper, and costs are likely to continue to decrease over the next thirty years. It does take a lot of space to catch the light of the sun directly. In sunny areas like California, Spain and North Africa, solar energy can already compete with fossil fuels. Space used for solar panels, the roof, is usually free, no transport costs need to be paid and the electricity is not taxed.

Large scale application, for example for industrial purposes, is currently still significantly more expensive than energy from wind or biomass, although this does depend on location. Aside from photovoltaic solar panels, another form of harvesting solar energy is becoming increasingly attractive for large scale application. This is Concentrated Solar Power (CSP), in which mirrors are used to concentrate the sunlight on a single spot. The resulting heat is used to power a steam turbine that in turn generates electricity. A number of large companies in Europe have advanced plans to construct large CSP plants in North Africa. These plants would mainly generate electricity for Europe, and involve hundreds of billions of euros in investments.

*Biobased economy*

In a ‘biobased economy’, products that were previously made from petroleum are made with green resources, like biomass from plants, trees and algae. This transition has already started with the creation of biologically degradable material and biogas made from manure and maize.

There are two ways in which a biobased economy contributes to reducing greenhouse gas emissions. Firstly, the growth of algae, plants and trees removes $CO_2$ from the atmosphere and stores the carbon in the plant material. Secondly, making products out of biomass should (at least in theory) require a lot less energy than making them out of petroleum. Quite a bit of research is still needed to capitalize on these gains by designing the most efficient processes.

The development of a biobased economy can offer economic opportunities for some countries. The Netherlands, for example, has a strong agricultural sector and a strong chemical industry; cooperation between the two is at the core of biobased economy. Furthermore, a transport network is necessary to enable shipping the large quantities of biomass required. On the downside, producing these amounts of biomass takes up a lot of space. This is especially problematic in countries with a high population density, where space is usually expensive. This means that a large part of the necessary biomass for these countries would have to be imported from other countries. This takes up space in other parts of the world.

This gives rise to the most often heard argument against a biobased economy: why would you use arable land for producing energy, when you could use it to grow food, especially when almost a billion people are suffering of hunger worldwide? Theoretically, there is enough space for both if the arable land and its produce are used efficiently. But this is not necessarily so. It will be an enormous challenge to control the tensions that will probably arise between food on the one side and energy and a biobased economy on the other side.

*Geothermal energy*

There are three ways to use underground high temperatures as a source of energy. The first is to use it for heating and cooling of our houses and other buildings. In this solution the ground, down to a depth of 100 metres, is used as a buffer to store heat or cold. Using a heat pump (a sort of inverted refrigerator) either cold or heat is brought up into our buildings in order to reach the desired temperature. A heat pump does require electricity to operate, but it is far more energy efficient than traditional heating or cooling with natural gas or electric air conditioning.

A second way to use geothermal energy is for heating greenhouses and large buildings. This involves tapping into deeper layers of the earth’s crust, down to a depth of approximately three kilometres, where the temperature is around 60 to 70 degrees Celsius. By pumping water through these layers and then up into the greenhouses and buildings, these are heated up directly by the underground heat. Horticulturists especially are enthusiastic about this source of energy.

The third form of energy from underground geologic formations is applied in Iceland: as a result of cracks in the earth's crust, the hot substrate layers are very close under the surface. The geysers in Iceland show how much energy is available from these layers. Technological advances have made it possible to tap into this source of energy even in places where these layers are deeper, for example over six kilometres deep. The temperature in these layers varies between 120 and 160 degrees Celsius. By conducting water through these layers, steam can be produced to power a turbine.

Global interest in geothermal energy is on the rise. This development is most advanced in places where the hot layers are close to the surface, like the Philippines, Indonesia and Turkey.

*Tidal energy, wave energy, hydropower and osmotic power*

Tidal energy and wave energy appeal to the imagination because the sea harnesses a lot of power to which the wind adds even more energy. However, extracting this energy turns out to be difficult. There have been many experiments across the globe with different methods of extracting energy from waves and currents, but the high costs continue to be an obstacle. It is economically interesting only in case of a large tidal difference (five metres or more), strong tidal flows (more than two metres per second), or continuous high waves.

The problem with extracting energy from rivers or seas is that large investments are required in order to build the constructions necessary for capturing the forces of (running) water and/or waves. Furthermore, maintenance is expensive due to the problems of sedimentation and corrosion and biological accretion that occur in aquatic conditions.

'Blue energy' is a term used for osmotic power, a form of energy which stems from the difference in salt concentration between seawater and river water. This energy can be extracted by letting separated salt and sweet water pass along a very thin membrane. Because of the differences in the concentration of salt, electrons tend to jump across. Electricity is generated by catching these electrons in the membrane. This form of energy generation may be interesting in river estuaries, where large quantities of sweet water come in contact with salt water. However, several questions remain to be answered. Areas that are suitable for this type of energy generation are usually rich in suspended sediment and organic life. The impacts that filtering the water has on the efficiency of the system and the surrounding ecology are not yet clear. Experiments with small test installations are currently ongoing.

**Mobility and transport**

An important part of our energy consumption stems from transporting people and goods. The issue of how we will transport ourselves in the future, say thirty years from now, is hotly debated. Will we still be driving our own cars with (more efficient) fuel engines, or will our entire transport be automated and if so, will it be all electric? Will goods still be transported across the globe, or will we produce everything locally and will it be only knowledge that travels (digitally) across borders? Will we travel by plane more, or will communication and recreation increasingly take place in cyberspace?

On a shorter term, one important question is whether electric cars and busses will have a leading position in transporting people in ten years. Electric mobility is roughly twice as efficient as driving on petrol or diesel. This makes electric cars attractive, even without taking into account the climate change angle.

At the same time, the combustion engine will not go down without a fight. Car manufacturers and oil companies have been working hard in recent years to make cars more fuel efficient. A significant part of the revenue generated by large international oil companies comes from the production and sale of petrol and diesel. It will be interesting to see which concept eventually wins the race.

For trucks and ships, electric transport is highly unlikely to be the solution. Liquid energy and (compressed) gas have a higher energy density (meaning they store more energy per kg) than batteries and can be refilled more quickly. Biofuels and biogas appear to be the most interesting alternatives for this mode of transport in a climate neutral economy.

One of the most challenging questions is how air transport can be made climate neutral. For approximately ten years now, passengers are being offered a growing number of possibilities to offset the carbon emissions created by their trip with credits. These credits are then used to plant trees, or to limit $CO_2$ emissions elsewhere. During the last couple of years, airlines and engine manufacturers have started experimenting with alternative fuels. The main focus is on biofuels: these can be used to produce kerosene fairly easily. Large investments are made in this field. One of the lines of investigation examines the potential of growing algae for kerosene production. It will take several decades before air transport can be completely climate neutral. This is not limited to $CO_2$ measures only, but also involves mitigating the effect of water vapour and other exhaust gases on the radiation balance.

**What about the other greenhouse gases?**

The discussion about climate change is largely focussed on $CO_2$. This is understandable, as $CO_2$ has made a significant contribution to the increase in greenhouse gases. However, concentrations of $CH_4$ (methane gas), another greenhouse gas, have also risen sharply. Methane is released by wet rice fields, ruminant cattle and waste. The impact of different greenhouse gases on our climate is usually expressed in $CO_2$ equivalents. The concentration of methane is much smaller than that of $CO_2$, but the influence per molecule is larger than that of $CO_2$. And the impact per molecule of nitrous oxide ($N_2O$), which is released from artificial fertilizer, is larger still.

Data concerning the source of these additional greenhouse gases has been displayed earlier in figure 1. This figure shows that the use of fossil fuels is the largest contributor. Agriculture and the food supply chain especially make significant contributions to greenhouse gas emissions. When peatlands are converted for agricultural use, they are drained for improved accessibility. This exposes the top layer of peat and causes oxidation (burning without fire). Just as if the peat was burned, this process releases $CO_2$. At the same time, the ground level declines due to dehydration and oxidation. This makes the ground wetter and more difficult to access. In response, farmers further drain the land to lower to the water level, with more oxidation as a result. In some areas, this repeated process has lowered the ground level by several metres, while at the same time emitting large quantities of $CO_2$ into the atmosphere. In recent years, increasing amounts of peatland have been taken into productive use across the world. In Indonesia, for example, this process of land conversion makes up a large part of national $CO_2$ emissions.

The way in which global land use and food supply will develop has a marked impact on the flow of greenhouse gases. It impacts both emissions and the capacity of the earth to absorb greenhouse gases. Reducing emissions and increasing the absorptive capacity of soil and vegetation is by no means an easy task. The cattle industry is a large source of methane emissions as well, both through the cattle itself and the manure they release. The worldwide growth of meat consumption comes with a parallel growth in greenhouse gas emissions from this sector.

**Should we eat less meat?**

Research has shown that meat consumption causes four to six times more greenhouse gas emissions than a vegetarian diet. In the hypothetical scenario of the entire world population switching to a vegetarian diet, greenhouse gas emissions would drop by as much as 20 percent; see figure 37.

In rich countries, a trend can be discerned of people limiting their meat consumption for reasons of health and ecology. Reducing the amount of greenhouse gases turns out to be one these reasons. At the same time, people in rapidly developing countries like China are starting to eat more meat. This involves a far greater number of people. Organisations that concern themselves with food and agriculture, like the FAO in Rome, are starting to become aware of this issue. There are solutions, but these will require a large change of personal attitudes and cultural beliefs, probably even more so than the changes to our energy system.

## THE IMPACT OF MEAT CONSUMPTION ON FUTURE $CO_2$ EMISSIONS

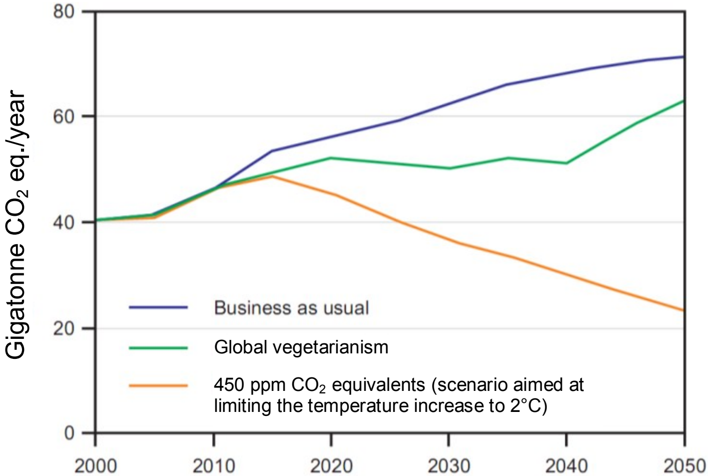



*Figure 37.This figure shows the impact of a worldwide switch to vegetarianism on global greenhouse gas emissions. Such a transition would close roughly 25 percent of the gap between business as usual and the 2 degrees target. [Source: Stehfest e.a., Climate Change (2009)[47]]*

# 8

## *Facts, myths and the real uncertainties*

There is a widespread interest in climate change: everyone has an opinion about it. In the discussion on this complicated subject, ideas, opinions and scientifically founded insights often crisscross one another. In this chapter, a number of controversial insights and opinions will be held to light. The chapter starts off with a small number of facts: scientifically measured insights that even climate critics generally accept as fact. This will be followed by some myth busting. Here, a number of conventional ideas, arguments and opinions will be put to the test with scientific rigour. Lastly, the true uncertainties, the ones that climate researchers are primarily concerned with nowadays, will be discussed.

### Facts

Scientific insights generally have been put to the test through a variety of experimental and theoretical methods. When these tests keep showing the same results, we are quick to accept these insights as facts. The word “fact” in and of itself can lead to confusion, because some people assume facts are merely subjective constructions of reality. Naturally, this makes it difficult to have a discussion. In this chapter, facts are defined as findings that have been tested or measured with the same results repeatedly and by different people.

The first fact is that the concentration of greenhouse gases in the atmosphere has risen sharply since we started measuring them in 1958. The second fact is that these gases have been shown in laboratory tests to allow the heat that comes from the sun (with a short wavelength) to pass through freely, while simultaneously inhibiting the warmth radiating from a hot object (infrared radiation, with a longer wavelength). The third fact is that the molecular properties of a large part of the additional greenhouse gases found in the atmosphere point directly to fossil fuels as their source.

These three facts can be verified every day by way of experiments and measurements. The results will confirm the facts time and time again.

Time to bust some myths.

### Myth no. 1: the warming effect of $CO_2$ is merely a hypothesis

In the media, but also in politics, the effects of greenhouse gases are often presented as "merely a hypothesis"; a supposition you can subscribe to when much remains unknown on the subject, and which is only as valid as every other supposition.

Measurements of the properties of these gases in laboratories, however, demonstrate that the warming effect of these gases is much more than just a hypothesis. As early as 1860, the inhibiting effect of $CO_2$ on heat radiation was demonstrated in a laboratory. The Englishman John Tyndall was the first to describe this effect in his book *Contributions to Molecular Physics in the Domain of Radiant Heat*, in 1872.

His observations confirm the laws of the theory of radiation in physics.

Laboratory tests showed that certain gases, the so-called greenhouse gases, allow solar energy to pass through freely, while those same gases have an inhibitory effect on invisible heat radiation (infrared radiation). In other words, a hot object loses its heat less quickly when surrounded by greenhouse gases. Infrared radiation is the heat radiation we feel when we are standing close to a hot radiator. Laboratory tests and the theory of radiation show that the inhibitory effect of greenhouse gases increases with an increase in the concentration of these gases.

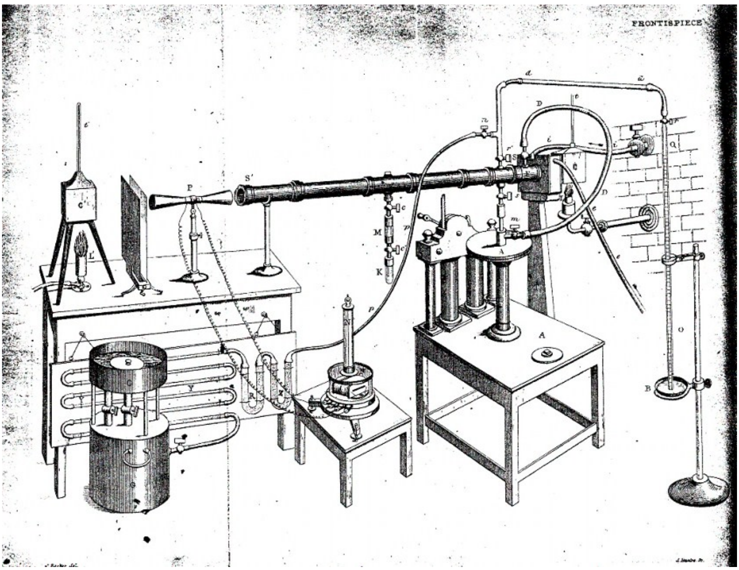



*Figure 38. The test setup used by John Tyndall to prove the greenhouse effect in the 1850s. This figure was taken from*

*his book* Contributions to Molecular Physics in the Domain of Radiant Heat *from 1872.*[48]

The big question now is whether the effect of greenhouse gases on a laboratory scale translates to the larger scale of the earth. This is not self-evident: other gases play a part in the radiation balance of the earth, too. Furthermore, there are geological and meteorological processes that can reinforce or dampen the effect of greenhouse gases.

It is hard to experiment on the scale of the earth. Immediate proof of the inhibitory effect of greenhouse gases in the atmosphere can therefore not be produced. However, in the past thirty years research has produced four different, independent observations which support the thesis that $CO_2$ also has an inhibitory effect on a planetary level, and that an increase in the concentration of $CO_2$ and other greenhouse gases leads to an increase in the average temperature at the earth's surface. These observations will be illustrated briefly below, under the numbers 1 to 4.

*1. $CO_2$ on other planets*

The effect of greenhouse gases on other planets has been measured extensively and described scientifically decades ago, when we first started traveling to the moon and exploring the planet Mars. Using astrophysical calculations, a fairly accurate calculation can be made of the expected temperature of the earth and other planets based on their distance to the sun. The actual temperature deviates from this expectation due to the atmospheres around the planets. The composition of these atmospheres is well-known by now.

We know, for example, that the amount of greenhouse gases surrounding the planet Venus is much higher than that surrounding the planet Mars; earth is somewhere in between. When the radiation theory developed in laboratories is applied to these two planets as well as to earth, the calculated temperatures turn out to match the actual measured temperatures very closely. This correspondence greatly supports the thesis that $CO_2$ has the same effect on a planetary scale that it has in the lab.

*2. $CO_2$ and the temperature in earth's geological history*

More proof supporting this thesis comes from the earth itself. In the geological past, there have been periods during which the concentration of $CO_2$ was higher than it is at present. It was also warmer back then. Temperature changes in the distant past can be determined with great precision from the isotope ratio[49] of the oxygen present in silt samples taken from the ocean floor. The development of the concentration of $CO_2$ in the atmosphere can be reconstructed as well, among other things by analysing air bubbles stored in age old ice formations. Measurements of the development of the concentration of $CO_2$ in the atmosphere in earth's geological past clearly show that there is a correlation between the concentration of $CO_2$ and the temperature on earth. For example, we know from various lines of research that the earth was much hotter during the period when there were dinosaurs on earth, and that the concentration of $CO_2$ was much higher as well. Furthermore, the composition of the air samples from the ice sheets and the oxygen from silt samples taken from the ocean floor show that during the transition from ice ages to interglacials and vice versa, the concentration of greenhouse gases rises and falls accordingly. This does not prove that there is a causality, as has been comprehensively discussed in chapter 4. It is therefore not a direct proof, but it does support the argument that the effect of greenhouse gases in the lab translates to the scale of the earth: higher concentrations normally lead to higher temperatures. If an increase in $CO_2$ has no effect on temperature, we would be likely to find periods during which rising concentrations were accompanied by a drop in temperatures. These periods have not been found on the time scale relevant to climate change: decades to hundreds of years.

3. *Satellite measurements of the effect of greenhouse gases in the atmosphere*

Satellite measurements in the present day also support the thesis that $CO_2$ has a warming effect in the atmosphere. Using satellites, researchers have measured that the greenhouse gases in earth's atmosphere do indeed have the same effect that they have in a laboratory setting. Satellite measurements show that the concentration of these gases has increased, and that the inhibitory effect on infrared radiation is in line with calculations for a further increase of the earth's temperature in the future.

4. *Measurement of the earth's rising temperature since 1990*

The warming of the earth during the past few decades is in line with the calculations made beforehand based on the greenhouse theory. These calculations were published in the IPCC's first report in 1990, and, as mentioned before, predicted an increase in temperature of 0.15 to 0.2 degrees Celsius per decade. Now, twenty years later, the earth should be 0.3 to 0.4 degrees warmer based on their calculations. Of course, natural variations in temperature can cause reality to deviate from these expectations. Nevertheless, the fact is that since 1990 the actual measured temperature at the earth's surface has risen by 0.3 to 0.4 degrees. This strongly supports the method of calculation used to predict the effect on temperature of additional greenhouse gases.

**Alternative explanations do not hold up**

One of the alternative theories about the effect of greenhouse gases which has been put forward is that the warming effect of these gases is largely or even entirely compensated by the cooling effect of the evaporation of water. This theory has been disproven many times, but still resurfaces every now and then. In 2011, Dutch researchers from the KNMI, Utrecht University and several other institutes systematically re-analysed this theory, as well as other theories on the warming of the earth, and compared them to measurements. The results of this research were summarized in a report titled *De Staat van het Klimaat 2010* (The State of our Climate 2010).[50] The results show that none of the alternative theories hold up. *De Staat van het Klimaat 2010* discusses, among other things, the work of Ferenc Miskolczi. Based on a radiation theory he developed himself, this researcher argues that the presence of greenhouse gases does not lead to a warming of the earth.[51] However, a comparison of his theories and measurements with proven scientific principles led the KNMI's meteorologists and physicists to the conclusion that Miskolczi's radiation theory contains fundamental errors – see also the PCCC (Platform on Communication about Climate Change)'s website, and the website www.realclimate.org.

Another story questioning the IPCC's calculations is provided by scientific journalist Marcel Crok. In 2010, he published a book which he gave the same title as the report published in 2006 by Dutch scientific institutes: *De staat van het klimaat*. Based on a rather personal interpretation of the scientific literature, he questions the warming of the earth. He points out the flaws in past temperature measurements, as well as the underestimated influence of the sun and air pollution. He does, however, acknowledge the quality of the more recent satellite measures since 1978, and the 0.5 degree Celsius increase in temperature that has been measured since. An important omission in Crok's story is that he disregards the delayed effects of greenhouse gases, by assuming that the current temperature is in complete equilibrium with the current concentrations of greenhouse gases. Crok's conclusion is that we will not see a temperature rise higher than 1 degree Celsius by 2100. He adds that this is so insignificant that there is no reason to invest in climate neutral energy now. These conclusions are open to discussion, especially because the most reliable measurements available show that the temperature has already risen by 0.8 degrees Celsius. In light of this, the odds of the eventual temperature rise being limited to 1 degree are incredibly small. To put a positive spin on it, one could call Crok an optimist and a wishful thinker. More objectively, he has been picking and choosing from the available scientific literature.

**Myth no. 2: it is not getting warmer at all; temperature measurements are faulty**

The quality of temperature measurements has long been a point of contention. A number of scientists have claimed that the temperature rise measured so far has been the result of urbanization around the weather stations where the thermometers are situated. It is true that urbanization has an influence on weather stations. However, during the last 30 years increasingly adequate corrections have been made in order to compensate this. Even after these corrections, there is still no doubt that the global average temperature has increased, especially since 1970.

Different research groups around the globe determine the average temperature on earth every year. They do not all use the same methods, which is why their findings differ. These differences are small, however, and the general trend is the same for all methods. Since 1978, satellites are being used for measurements as well. They can measure a complete, worldwide temperature signal. These satellite measurements are being compared to the traditional measurements made using advanced thermometers. These comparisons show that the results match quite closely. Figure 39 compares the

## GLOBAL TEMPERATURE DEVELOPMENT 1900-2100

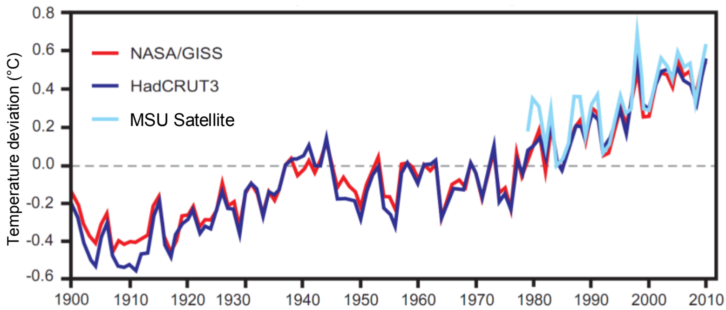



*Figure 39. The global average temperature deviation as compared to the 1961-1990 average, measured in different ways. NASA/GISS and HadCRUT3 show a combination of data from global weather stations (sea water temperature and air temperature measured 2 metres aboveground). Different satellites with an MSU-instrument measure an average temperature over the lower 8km of the atmosphere. [Source: KNMI[52]]*

results of the different measurements. Based on these different series of measurements, it is hard to deny the fact of global warming. Even most climate sceptics accept the measurements taken since 1978 as displayed in figure 39. These measurements prove that the temperature on the earth's surface has risen by 0.5 degrees Celsius since 1978. This warming is confirmed by the shrinking of nearly all glaciers on all continents, thawing permafrost areas and rising ocean temperatures. The idea that the earth is not warming up should therefore be considered a myth.

Occasionally in this discussion confusion arises over the areas taken into account. Where rising temperatures caused by additional greenhouse gases are concerned, we are always talking about the global average temperature on the earth's surface. Not all parts of the earth are heating up at the same rate; some heat up faster, some slower. The United States saw a relatively cold 2010, while the global average temperature in 2010 was one of the highest on record.

**Myth no. 3: it is not the presence of greenhouse gases, but rather the sun that is causing the earth to heat up**

Every couple of years, the suggestion that the sun is causing the warming of the earth is brought forth again. The people who suggest this usually are not denying the fact of global warming, but want to contest the cause of it, downplaying or even outright denying the influence of additional greenhouse gases. To support this thesis, data pertaining to past sunspots gets reinterpreted to support the assertion that the sun "has been playing a warming role up until recently, and will be playing a cooling role in the future". This conclusion has been made every year for the past fifteen years, and yet this "cooling phase" has yet to show up in actual measurements, which makes this assumption look less and less believable.

As mentioned before, there are indeed indications that variations in solar intensity have had some impact on the average temperature, but research also shows that their role is minor. Sun activity will continue to influence temperatures, but this influence is small compared to the influence exerted by the growing concentrations of greenhouse gases.

Essentially, different arguments and statistics have been used to speculate on the effects of the sun without a clear scientific basis. One thing we do know for certain is that the warming pattern around our planet and the way it has developed over the past hundred years is much better explained by additional greenhouse gases than it is by the effects of the sun – remember figure 15 in chapter 3.

**Myth no. 4: switching to climate neutral energy will endanger the economy**

There is some truth to the idea that sustainable energy is expensive, but if we look at the economy as a whole, we get a different picture. After all, investing in non-renewable energy sources is expensive as well. It is a matter of weighing the costs and benefits, as discussed in chapter 7.

During the past decade, many studies have been done into the costs and benefits of switching to climate neutral energy. These studies show that this will indeed require significant investments. However, they also show again and again that the effect of these investments on economic growth is extremely small: less than 0.1 percent annually. Calculations made by the International Energy Agency in Paris, the previously mentioned McKinsey study, and research done by the Dutch Regieorgaan Energietransitie [53] (the energy transition management body, in which corporations cooperate with research institutes), all show that the transition to climate neutral energy will not endanger the economy. On the contrary, it will create opportunities for innovation and revitalization of the energy economy.

**Myth no. 5: sea levels could rise significantly in the next 30 years**

The idea that sea levels could rise by several metres in the next 30 to 50 years is based on a misunderstanding. This "fact" has been reported by the media more than once, but it is based on a confusion of two separate facts. One is that the warming up of the earth could, indeed, cause sea levels to rise by several metres, but on a much longer term (hundreds of years). The other is the fact that the greenhouse gases which will be released in the next 30 to 50 years could determine this long term rise in sea levels. It concerns the possibility that we will reach a turning point during this period, after which we will not be able to stop the ice caps from melting further. Therefore, the next 30 to 50 years could be crucial in regards to the future of the ice caps.

The rising of the sea levels is a slow-starting process, but once begun it is hard to stop. Because the process is relatively slow, we are not likely to see a rise larger than 15 to 35 centimetres in the next 30 to 50 years. However, because it is a slow process, it will continue for a long time. After the year 2050, the speed with which the sea rises could potentially increase, reaching a speed of multiple metres per century in the long term. That this is possible is proven by sea level rises in the past, approximately 12,000 years ago, when the average world temperature was 1 to 2 degrees higher than it is now. Then, the rising sea levels had a natural cause. At present, we are talking about the effect of additional greenhouse gases.

**Myth no. 6: climate change poses a severe threat to life on earth**

The idea that climate change as a result of greenhouse gases poses a severe threat to life on earth is a popular myth. Nonetheless, there is little base for this myth; a warmer earth will still support abundant life. One need only look at the warmer ages that have occurred throughout geological history, when dinosaurs roamed. Climate change mainly impacts the way we humans live our lives. Cities in low-lying areas will have to cope with flooding much more often. Inhabitants of small island states might have to give up their land. Agriculture and food supply will be threatened by drought. Higher temperatures and lasting drought will mean a higher occurrence of forest fires (see for example figure 40), which may also be more widespread. Climate change also threatens biodiversity as we know it. There will be damage - grave damage, even, but the earth and its ecosystems will repair themselves eventually, even after such a significant change.

**SMOG DUE TO FOREST FIRES IN RUSSIA**

*Figure 40. A long drought combined with extreme temperatures caused extensive forest fires in Russia during the summer of 2010. [Image: The Telegraph[54]]*

**The real uncertainties**

When trying to estimate by how many degrees the earth will have warmed up by the year 2100, there are four factors which are largely uncertain:

- How many greenhouse gases will be released into the atmosphere in the next 50 to 100 years?
- How many of these gases will remain in the atmosphere?
- What is the influence of these additional greenhouse gases on the atmosphere, and on the rise of the average temperature on earth?

- How will consumers, corporations, and politicians both on a national and international scale react to climate change and its projected effects in the coming decades?

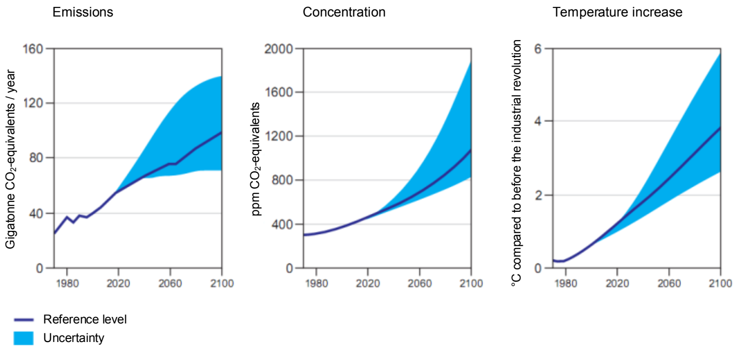



*Figure 41. Uncertainties regarding the warming up of the earth in three categories: a) greenhouse gas emissions, b) greenhouse gas concentration, and c) the effect of these additional greenhouse gases on the average temperature at the earth's surface. [Source: PBL(2009)[55]]*

The range of possibilities regarding the first three points is illustrated in figure 41. On the way society will react to climate change, we can only speculate.

**Uncertainty no. 1: how many greenhouse gases will be released into the atmosphere in the future?**

It is not just the use of fossil fuels for energy which releases greenhouse gases. Agriculture, livestock farming and waste management also release greenhouse gases; remember figure 1 from chapter 1. Additionally, natural processes play their part. For example, how many greenhouse gases will be released if the Russian tundra melts? Nobody can give a precise answer to that. In 2004, the use of fossil fuels was responsible for 60 percent of the (effective) increase in greenhouse gas concentration in the atmosphere. Additionally, deforestation, drainage and oxidation of peatlands, livestock farming and waste management also make a significant contribution. How these various activities and the practices and technologies attendant on them will develop in the future strongly depends on the choices we make in the near future. This means the margin of uncertainty in this area is fairly wide. See figure 41 (left): the top of the margin area represents the situation if the current economic trends continue and the use of traditional fuels as well as traditional methods of agriculture are maintained. The lower edge of the margin represents the situation in case economic trends are bucked and/or we switch to different fuel sources.

As we can see, there are significant uncertainties at play here, which cannot be solved by further research.

**Uncertainty no. 2: what percentage of greenhouse gases released into the atmosphere will stay there?**

Currently, half of all greenhouse gases which are released annually are reabsorbed by oceans and vegetation that same year. The question is whether this will continue to be true in the future.

In figure 42 we see the growth of the concentration of $CO_2$ in the atmosphere since 1958. The yearly variation shows the changing of the seasons. In summer, forests and vegetation absorb a lot of $CO_2$; in winter, when the leaves fall from the trees, a lot of that $CO_2$ is released back into the atmosphere. Because the Northern Hemisphere has a greater landmass, and thus more forests and vegetation, the Northern Hemisphere's summer is more clearly visible in the measurements. And because $CO_2$ spreads rapidly, the dominance of the Northern Hemisphere's seasons also shows in the $CO_2$ concentration in the Southern Hemisphere.

**INCREASED CONCENTRATION OF $CO_2$ IN THE ATMOSPHERE**

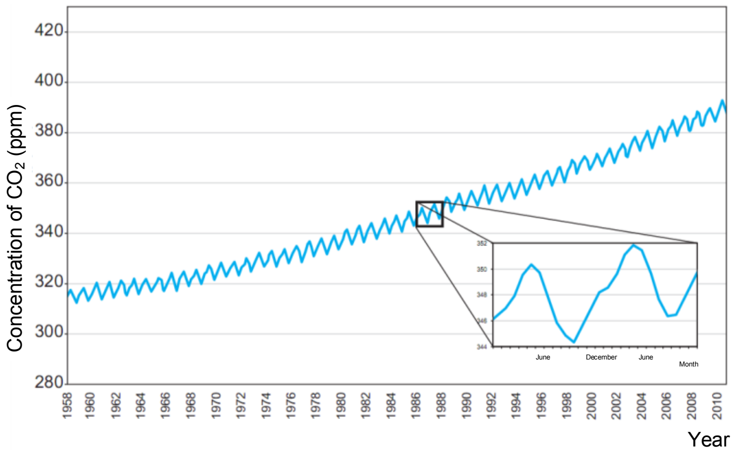



*Figure 42. The measured increase of the average monthly concentration of greenhouse gases in the atmosphere in Mauna Loa, Hawaii. The enlargement clearly shows the influence of the seasons.*[56]

The natural flow of $CO_2$ from earth into the atmosphere and back is much larger than the amount that is added by people every year. The oceans absorb approximately 92 gigatonnes of carbon annually, and release approximately 90 gigatonnes back into the atmosphere. Forests and other vegetation absorb over 120 gigatonnes and release slightly less than that with the changing of the seasons. Human activity produces an annual 8 gigatonnes of carbon, in the form of $CO_2$ and $CH_4$. Approximately half of this remains in the atmosphere; remember figure 23 from chapter 4.

Whether nature will continue to absorb half of all $CO_2$ emissions produced by human activity depends on how vegetation, the soil and the oceans will respond to the increased presence of $CO_2$. This response likely depends on the earth's temperature and the amount of $CO_2$ in the atmosphere. In most calculation models it is assumed that the earth will continue to absorb approximately half of our $CO_2$ emissions. However, there are researchers who convincingly argue that a warmer earth will absorb less $CO_2$.[57]

Exactly what amount of greenhouse gases will be absorbed by vegetation, the soil and the oceans in a warmer world is one of the important research questions of this day. The answer to this question is of significant influence to the final rise in temperature.

**Uncertainty no. 3: how sensitive is our climate system to additional greenhouse gases?**

The question of how sensitive the earth's average temperature is to changes in greenhouse gas concentrations is the main scientific uncertainty we are facing at this time.

In the earth's geological history, there have been times when there was more $CO_2$ in the atmosphere than there is currently. And the earth was indeed warmer during these periods of time. However, it is not entirely clear what caused this increase in $CO_2$, or how this increase relates to the warming up of the earth's average temperature.

Water vapour plays an important part in calculating the climate system's sensitivity to additional greenhouse gases. $CO_2$ may be our society's main contribution to greenhouse gas concentration, in the end water vapour ($H_2O$) makes a much larger contribution to the warming up of the earth. This works as follows: according to the laws of physics, warmer air can hold more water vapour than colder air. There is plenty of water on earth, so the average concentration of water vapour in the atmosphere will adjust to the average air temperature. Due to the increase in $CO_{2,}$ the temperature of the earth and the air around it will rise. Because of this, the average concentration of water vapour will rise as well, which means temperatures will rise even further. $CO_2$ initiates the change, water vapour follows with the rise in temperature.

Aside from its function as a greenhouse gas, water vapour also plays an important part in forming clouds, which in their turn affect how much sunlight comes in, and thus influence temperatures. As such, water vapour has a multilateral influence on the average temperature. The warming effect is the most significant, but the dampening effects of clouds make it hard to make a precise estimation of the net effect. This net effect will depend largely on where this extra water vapour will end up. More water vapour on cloud level would limit the exacerbating effect; clouds may cause warmer night temperatures, but during the day they have a cooling effect. More water vapour on higher altitudes, on the other hand, would cause a rise in temperatures. No clouds form there; instead, water vapour will take on the form of a light mist, which reinforces the greenhouse effect. A large part of the disparity between the predictions for the temperature rise in 2100 comes down to this uncertainty: how much water vapour will be released, and especially: where will it end up?

The warming up of the earth does not just concern these kinds of natural processes, which follow the laws of physics. The chemical composition of the atmosphere and the effect of air pollution on the radiation balance (and thus temperatures) also play a significant part. The particles that are released (along with $CO_2$) during combustion processes have both a cooling effect and a warming effect. The net effect is almost certainly cooling, which means that part of the current greenhouse gases-induced warming is being masked by the cooling effect of air pollution. When the air becomes cleaner, the average temperature will rise. These kinds of processes make the issue both scientifically and socially complicated. Nevertheless, it is possible to do research in order to reach greater insight into this matter.

For instance, researchers find it scientifically interesting when all air traffic on a specific continent is grounded, as was the case for several days after the attacks on the Twin Towers in 2001. Thanks to satellites which continually collect data, this yielded a wealth of information.

Lastly, there is uncertainty about the so-called tipping points in our climate system. The more temperatures change with respect to the situation as it has been for the past 10.000 years, the harder it becomes to predict the effects. There are almost certainly several non-linear reactions at play, and the manner in which these interact makes it hard to calculate the eventual degree of global warming.

Because of global warming, the earth loses snow- and ice surfaces, which diminishes the previously explained albedo effect. Because of the disappearance of snow and ice, the earth’s surface becomes darker and thus absorbs more of the sun’s warmth. At the same time there are other influences, such as deforestation and overgrazing, which cause the earth’s surface to become lighter and thus reflect more sunlight. There is uncertainty regarding the net impact of this effect. Research can increase our insight into these processes.

The manner in which the oceans absorb and distribute heat is probably the main source of uncertainty when it comes to the rate at which the earth warms up. The intensification of the greenhouse effect means that the oceans’ top layer will rise in temperature. Initially, this mainly concerns the top layer, which is stirred by waves and wind-driven currents. This layer is over 100 metres deep. However, this layer slowly mixes with the deeper layers, by means of horizontally and vertically meandering currents spanning the globe. These “rivers” and “waterfalls” within oceans cause a slow but continuous mixing of water. This is a slow process, taking centuries or more. The main questions occupying oceanographers are: how much warmth will remain in the upper layers of the oceans, how much warmth will mix with the lower layers, and at what rate do they mix?

The four factors mentioned – the role of water vapour, the effect of air pollution, the change in the reflection of the earth and the mixing of warmth in the oceans – are responsible for a large part of the uncertainty regarding the degree and rate of climate change. We can influence greenhouse gas emissions and air pollution, but the other factors are more elusive.

The influence of human activities on our climate system can be reduced drastically, if we make radical changes across the globe. If we manage to reduce greenhouse gas emissions by 80 percent before the year 2050, according to current scientific insights there is a reasonable chance that the increase in the average global temperature by the year 2100 will be limited to 2 degrees Celsius. If emissions continue unabated, estimates vary between a 3 and 6 degree rise by 2100. The large margin of uncertainty is mainly caused by uncertainties in our understanding of the four processes described above.

**Uncertainty no. 4: how will the various countries of the world deal with the issue?**

Politically speaking, the crucial question is how the various countries of the world will deal with the issue of climate change. Europe's contribution to greenhouse gas emissions is less than 20 percent; ultimately, the emissions of large, heavily populated countries such as China and India will be the deciding factor, even though the current rate of per capita emission in these countries is significantly lower than it is in the United States. In international negotiations, the developing nations make it clear that they expect the industrialized countries to take the first step in reducing their relatively large emissions; the United States and China especially are keeping each other in a headlock this way. Questions that arise in relation to this topic concern the rate of development of new technologies, how much the reduction of greenhouse gas emissions will cost, and how much money various countries all willing to spend. So far, countries which have taken the lead in implementing environmental measures have always seen an economical advantage. With climate change, however, this experience does not seem to be equally compelling to all countries.

# 9

## *The outlook*

Scientific findings are slowly but surely getting through to society. Early on, it became clear that there are winners and losers when it comes to climate change. Northern countries will benefit from a warmer earth, while southern countries, including Southern Europe, will have more difficult times ahead. Oil and coal producing countries stand to lose from a policy aimed at reducing $CO_2$ emissions. This could hinder the development of a shared international policy. Still, a shared vision is crucial for solving this global problem, which affects all countries.

With this thought in mind the International Panel on Climate Change was founded in 1988, with the intention to create a shared understanding of the current state of climate science by combining the findings of international scientists. The insights gathered in this way, including the uncertainties surrounding them, will be presented periodically to all governments worldwide. The first time this was done was in the year 1990. Two years later, in 1992, in Rio de Janeiro, the first major political summit about sustainable development was held. Climate change was one of the main topics. It was in Rio that the first international climate treaty was made. This treaty laid the groundwork for the Kyoto protocol, which was agreed upon in 1997. The Kyoto protocol contained relatively firm agreements between industrialised countries to reduce their $CO_2$ emissions by 5 per cent (compared to 1990) by the year 2010. This may not seem like much, but at the time emissions were actually growing in most countries, which meant a turnaround was needed to achieve this goal. The European countries and Russia achieved this target. Meanwhile, in the United States, which refused to sign the Kyoto Protocol, emissions increased by roughly 20 percent.

The Kyoto Protocol is valid from 1998 until 2012. New agreements have to be made about what happens after. To this end an international conference was hosted in Copenhagen in 2009, at which almost all heads of state were present. At this conference, general agreement was reached on limiting the influence of human activity on our climate to a maximum of a two degree Celsius rise in average global temperatures. How each country was to contribute to this target was not agreed on, despite this being the purpose of the conference.

At the 2010 meeting in Cancún, Mexico, and the meeting in Durban, South Africa in 2011, some progress was made. The intentions stated in Copenhagen were reaffirmed and anchored somewhat more firmly, but agreements on how the ‘available space’ for emissions was to be divided were again not made.

It remains to be seen whether countries will succeed in reaching binding agreements on who does what in a global effort to limit greenhouse gas emissions. There still are large differences between approaches, and the big players seem to be waiting for each other to make the first move.

**Why the US hesitation about emission reductions?**

Since the start of the political discussion about climate change in the late 1980s, the US have shown a strong aversion to European politics, which have been aimed at strong emission reductions from the start. Despite arguments from American scientists and reports from nationally and internationally renowned research institutes about the importance of emission reductions, both large corporations and the federal government remain wary of taking firm measures. The importance of the availability of inexpensive fossil fuels is still ranked higher than the risks of climate change.

Furthermore, people in the US fear a greater influence of both national and international government over the energy supply system. This fear, or rather distrust of the government feeds the effort to downplay the importance of the greenhouse effect. This attitude, and even more so the way in which important opinion leaders and interested organisations nurture this fear is described extensively by American authors Naomi Oreskes and Erik Conway in *Merchants of Doubt* (2010).[58] In this book the authors show that important opinion leaders, whom they call 'merchants of doubt', put strong emphasis on the uncertainties regarding climate change, creating an image that the cure (a controlling government) is worse than the disease (climate threat).

American reluctance can be traced back to these two elements: the importance of the continued availability of inexpensive fossil fuels, and concern about government intervention in the energy supply system. Initially this led to a discussion about climate science. Later on, the competitive position of the US entered the picture as well. The US demand that large developing countries, like China and India, comply with binding reduction agreements from the get go. Large firms in the US worry that $CO_2$ measures implemented in the States will give a competitive advantage to their rivals in Asia. But China and India will not commit to anything until the US, with its much larger per capita emissions, makes the first move.

**How will this continue?**

During the Copenhagen climate conference in 2009 international agreement was reached on a mutual target: limiting emissions by as much as is needed to keep temperature rise within 2 degrees Celsius. It was also agreed upon that the rich countries, which emit a lot of greenhouse gases, will give financial support to developing countries for three purposes: to invest in low emissions technology, to maintain forests as $CO_2$ reservoirs and to invest in adaptive measures. During the follow-up meetings in Cancún and Durban, these agreements were affirmed. Furthermore, a start was made in establishing the organisation necessary for executing the agreements. However, there has been little progress since.

Meanwhile, the concentration of greenhouse gases continues to rise, along with the resulting global warming. The year 2010 was one of the hottest years on record. At the same time, investments in sustainable energy are skyrocketing. Without any agreements in place, China is taking the lead in this development. Although this decelerates the increase of greenhouse gas emissions, it is not sufficient to reach the aforementioned targets. Reaching those will surely need additional legislation.

The scientific debate carries on, too. The IPCC takes a leading role in this and is tightening its procedures in order to prevent future mistakes. The organisation is preparing for its next report, due in 2013/2014.

Changes measured in temperature, rainfall and drought, icecaps and sea level rise will probably make sure that climate change will keep getting media attention and political focus. However, this will probably not be sufficient to force breakthroughs on an international level. Discussion at an international level will continue, but will mainly concern attempts to harmonise national and individual initiatives. It would seem that the action will mainly take place at a national level and through private sector initiatives. For European countries, this involves not only national but also European level. Five or ten years from now, the continuing advance of climate change will no doubt create an even stronger call for international governance, in particular because international businesses will eventually need a certain harmonisation of rules.

**Europe**

There is little progress in international negotiations, but many countries and companies are not sitting idly by; many of them are investing in new technologies. In time, these investments will pay themselves back. The investors assume that fossil fuels will remain expensive and that the climate change issue will not solve itself.

The challenge for researchers and entrepreneurs is to find solutions that serve multiple purposes; solutions where the costs are as a low as possible while the profits, in terms of climate change and elsewhere, are as high as possible. Seen in this way, climate change becomes a game of opportunities.

At both European and national levels the progress of climate change measures will depend on the success with which they are linked to other issues like energy security, price stability, reduced air pollution and improving the quality of the environment. Finally, it is also a matter of innovation and economic reform.

Whether there is enough time to halt the train of climate change is unsure. But continuing on the same path now that we are aware of the dangers does not seem prudent.

# *Epilogue*

In this book I have attempted to systematically investigate whether those who are sceptic of climate change are right in saying that we are overly concerned. Could it be that climate researchers are exaggerating the danger? Based on our experience with acid rain and the Club of Rome we cannot rule out the possibility. However, after over 30 years of research and more than 20 years of global warming, we can distinguish a pattern of warming that fits seamlessly with the predictions made twenty years ago. This cannot be contested. There is, however, uncertainty about how this process will continue: will the earth be 2 degrees warmer by the year 2100, or will it have warmed up by as much as 6 degrees? According to current knowledge, both extremes are equally likely.

I have also dealt with the question of whether it is true that the global average temperature is still rising. This fact has been questioned repeatedly after the cold winters of 2009-2010 and 2010-2011. Meteorological research shows us that the cold which was experienced in certain parts of the world was more than compensated for by higher temperatures in other regions. The Pacific Ocean, for example, was warmer than ever before, and in the area around Greenland more ice melted than had ever been recorded. Critics have pointed out potential weaknesses in temperature data, but the accuracy of modern day satellite measurements and the worldwide occurrence of warming related phenomena render this discussion moot.

The question of whether the sun might be responsible for the warming we have seen in the last four decades has also been extensively dealt with. The odds that this is true appear to be very small. All the data show that the pattern of warming we are seeing fits the effect of greenhouse gases far better than it does changes in solar activity.

The ice ages were the next topic of discussion: are these extreme periods not of far greater importance for climate change than the additional greenhouse gases? Data from early ice ages show that a new ice age is indeed likely to start in approximately 20,000 years. However, this ice age cannot be seen as a compensation for the expected rise in temperature over the next hundreds of years, since these two events occur on different timescales. Furthermore, measurements taken over the last 50 years show that the impact of fossil fuels on atmospheric $CO_2$ is already larger than the effect of an ice age.

The question remains whether a slightly warmer earth would truly be that bad. After all, does this not also have benefits? Yes, it has. However, the negative effects are far more extensive, especially if the earth warms up by more than two degrees. The problem does not so much lie in the fact that temperatures are higher; there have been times when the temperature on earth was as much as 10 degrees higher than it is now. The problem is that in our current time, people are living virtually everywhere, and ecosystems have developed that are adapted to the current climate. The best estimate is that the (world average) temperature will rise by 3 to 4 degrees by the year 2100 if $CO_2$ emissions continue as they are now. It could be a little more, it could be a little less, but in either scenario it is more than nature and human society can handle without huge damage and international political confrontations.

This may seem dramatic, and it is. Consequently we will need to focus not only on reducing our emissions, but also on adapting to climate change. In this, we are dealing with processes that take a long time to materialize. As such, there is time to take into account the inevitable consequences of climate change.

In the Netherlands the Second Delta Commission (Tweede Deltacommissie, an advisory board, commissioned to advise the government on water management in the face of climate change) issued an urgent advice on the safety of the country under different scenarios for sea level rise and changes in river outflow. The way it looks now, the country can be kept inhabitable for a long time to come, but only if the necessary measures are taken in time. These measures make the cost of living and working in the Netherlands higher, but not prohibitively so.

The question remains how much we should at the same time invest in measures to reduce emissions. This could be seen as a matter of analysing costs and benefits: how much investment is needed now in order to prevent climate damage in the future? The answer to this question is difficult to give, because we cannot accurately assess the amount of damage that might occur. Furthermore, the people who are affected by this damage are not necessarily the same people who reap the rewards of the continuing use of fossil fuels. As such, a cost benefit analysis only paints part of the picture. The other part is a matter of ethics: can we justifiably continue using a source of energy when we know that it causes damage to next generations and to people in other parts of the world?

The political leaders that gathered in Copenhagen in 2009 took a stance on this issue based on the most recent scientific insights. They want to limit emissions to such an extent that the rise of average temperatures is limited to 2 degrees Celsius. Later on, in 2011 in Cancun, the decision was taken to also further investigate the possibility of limiting the temperature rise to 1.5 degrees. These targets can only be achieved through a drastic reduction of greenhouse gas emissions, to the extent of 80 percent within 40 years.

Finally, I called attention to the greenhouse gas emissions that result from the way we use our land and from our food supply system. These emissions make up approximately 25 percent of our total emissions, but they are much less discussed than those that stem from energy consumption. It could turn out to be much more difficult to reduce these emissions than to reduce those related to energy. Land use does not only entail deforestation, but also drainage of low lying areas and ploughing of fields. Food related emissions come mainly in the form of methane gas from ruminant cattle, but also from manure. The use of artificial fertilizers is yet another issue. These are all issues that will probably become ever more pressing items on the political agenda.

Meat consumption appears to have an especially large impact on emissions, much more so than a vegetarian diet.

This book will have made it abundantly clear that climate change will keep us busy for a long time to come. A nice conversation topic, not unlike the weather, but less casual. The issue of climate change can largely be solved through innovation and technological progress, but only if we make the necessary investments and change our behaviour. At the same time, it is exciting to see how other people and other countries deal with climate change. For all who care to see it, there is plenty of work to be done!

Pier Vellinga

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# *Notes*

[1] Greenhouse gases are gas molecules that absorb heat. In the atmosphere, they function like a blanket that traps the earth's heat. $CO_2$ (carbon dioxide), $H_2O$ (water), $N_2O$ (nitrous oxide), $O_3$ (ozone), $CH_4$ (methane) and several CFCs are examples of greenhouse gases.
[2] The unit of the Y-axis is $CO_2$-equivalents: different greenhouse gases have different warming potentials, which can be expressed in terms of the amount of $CO_2$ required for an equivalent warming potential. Source: IPCC, AR4 synthesis report.
www.ipcc.ch/publications_and_data/ar4/syr/en/spms2.html
[3] The term 'additional greenhouses' is used throughout the book to signify those greenhouse gases that were released through human activity and remained there, causing concentrations to increase by 40 percent since the start of the industrial revolution.
[4] The terms '(average) global temperature' and 'the earth's temperature' are used throughout the book to indicate the (average) temperature at the earth's surface.
[5] The Intergovernmental Panel on Climate Change (IPCC) was started in 1988 by the World Meteorological Organisation (WMO) and the United Nations Environment Program (UNEP). Its mission is to make periodic reviews of the scientific base for understanding the risks of human induced climate change and possible mitigation and adaptation strategies. Independent experts judge existing scientific and technical knowledge and summarize their findings for policy makers. National governments (members of WMO and UNEP) agree on the focus and layouts of these periodical reports, select authors, discuss the results and agree on the 'summary for policymakers'. Creating the reports is an extremely complicated process, as it involves over a thousand scientists who (voluntarily) contribute to cover this broad topic. Source: Inter Academy Council (2010), *Climate Change Assessments. Review of the Processes and Procedures of the IPCC. IAC Committee to Review the IPCC*, October 2010.
[6] A dark, contrasting spot on the photosphere of the sun, which is dark because it is cooler than the surrounding areas. Even though

they are cooler, sunspots are associated with increased solar activity because the surrounding areas become hotter (see also www.swpc.noaa.gov/info/glossary.html and www.grida.no/publications/other/ipcc_tar/?src=/climate/ipcc_tar/wg1/244.htm).

[7] Average number of sunspots each month from 1900 till September 2010, presented together with the twelve month moving average. Source: Solar Influences Data Analysis Centre (Belgium). See http://sidc.oma.be/sunspot-data/.

[8] Fifty year average of the number of sunspots observed with the naked eye, among others in Europe, China, Korea, Japan, India, the Middle East and by the Mayans. The validity of these observations is questionable, and of course there will have been sunspots that were not observed. The Y-axis is different than that of figure 2, because of the way in which the numbers were calculated. This means that the graphs are not easily comparable. What matters are the movements within the individual graphs. Source: Vaquero (2007), 'Historical Sunspot Observations: a Review'. *Advances in Space Research.* Vol. 40 (2007), pp. 929-941.

[9] The official definition of El Niño is based on a temperature deviation in the area Niño 3.4, in the middle of the Pacific Ocean between Australia and Mexico. In case the three month moving average is half a degree higher than the average temperature there is an El Niño. If it is half a degree lower there is a La Niña. Source: www.esrl.noaa.gov/psd/gcos_wgsp/Timeseries/ and www.climatewatch.noaa.gov/2009/articles/climate-variability-oceanic-nino-index.

[10] http://news.bbc.co.uk/2/hi/in_pictures/6253114.stm.

[11] About 75 percent of La Niña's causes above average rainfall in Northern and Western Australia. In this specific case this rainfall caused floods that usually only happen once every hundred years. The NASA and NOAA websites have a treasure of information on this topic. See for example

www.climatewatch.noaa.gov/2010/articles/2010-la-nia-continuing-in-the-new-year/2, www.nasa.gov/topics/earth/features/strong-la-nina.html and www.nasa.gov/topics/earth/features/patzert-qa.html.

[12] Change in temperature compared to the average of 1980-1999. The grey band shows the 'best estimate', in this case ranging from the lowest projected increase under the B1 scenario up to the highest projected increase under the A2 scenario. Source: IPCC AR4, WG1. See: http://www.ipcc.ch/publications_and_data/ar4/wg1/en/figure-spm-5.html

[13] The Club of Rome still exists and can be found on www.clubofrome.org/eng/home

[14] The prognosis of $CO_2$ in the atmosphere is taken from the report of the Club of Rome; see figure 21 on page 66. Source: Meadows, D., D. Meadows, J. Randers, W. Behrens (1972), *Limits to growth.* Universe Books, New York. The actual values are yearly averages of measurements taken by NOAA on Mauna Loa (Hawaii). See: www.esrl.noaa.gov/gmd/ccgg/trends/.

[15] The yearly emissions of the following acidifying substances in the Netherlands: nitrous oxides ($NO_x$), ammonia ($NH_3$) and sulphur oxide ($SO_2$), expressed in kiloton ($10^6$ kilogramme) per year. Source: emissieregistratie (emission registration) (in Dutch): www.compendiumvoordeleefomgeving.nl.

[16] The hole in the ozone layer during the usual measurement month September in 1979, 1988, 2000 and 2010. The measurement unit (Dobson Unit) measures the amount of ozone you would find in a place if you were to go up in a straight column from the earth into space at a temperature of zero degrees centigrade and at a pressure of 1013.25 millibars. Source: NASA (http://ozonewatch.gsfc.nasa.gov/),

[17] Amount of Chlorofluorocarbons 11 (CFC-11; $CCl_3F$), 12 (CFC-12; $CCl_2F_2$) and 113 (CFC-113; $CCl_2FCClF_2$) in the atmosphere, expressed in parts per trillion. Source: measurements from Cape Grim,

Australia, Tasmanian Planning Commission, State of the Environment Report 2009 (http://soer.justice.tas.gov.au/2009/indicator/43/index.php).

[18] Deviation of global average temperatures as compared to the average over 1961-1990, obtained through three different measuring methods. NASA/GISS and HadCRUT3 give a combination of the surface temperature of the seas and the temperature of the air at two meters altitude above land. Several satellites equipped with MSU instrumentation measure the average temperature of the bottom eight kilometres of the atmosphere. The values for 2010 are the latest available figures while this book was written (January 2011). Source: KNMI (http://climexp.knmi.nl).

[19] Average temperature per decade, compared to the average temperature over the period 1961-1990. The height of each block indicates the uncertainty of the measurement. Source: Arndt, D. S., M. O. Baringer, and M. R. Johnson, Eds., '2010: State of the Climate in 2009'. *Bull. Amer.Meteor. Soc.*, 91 (7), S1–S224. (http://www1.ncdc.noaa.gov/pub/data/cmb/bams-sotc/climate-assessment-2009-lo-rez.pdf).

[20] Ever since roughly 1890 a trend is visible in which the average temperature of the bottom 15 kilometres of the atmosphere is heating up, while the upper layers (up to 30 kilometres altitude) are cooling down. The shaded boxes denote areas where the change in temperature is more than two standard deviations away from the average temperatures over 1001-2000 in a world without human influence on climate. This means that for those areas it is highly unlikely that the change in temperature is caused by natural phenomena. Source: Schwarzkopf, M.D. & V. Ramaswamy (2007), 'Evolution of Stratospheric Temperature in the 20th Century'. *Geophysical Research Letters*, Vol 34.

[21] See figure 9 on page XXII of the IPCC report of working group 1: Houghton, J.T., Jenkins, G.J. & Ephraum, J.J. (1990). *Climate Change. The IPCC Scientific Assessment. Intergovernmental Panel on Climate Change*, Cambridge University Press, 1990.

[22] The IPCC scenarios and the dataset 'IPCC report 1990' are taken from the *IPCC First Assessment Report* of: Houghton, J.T., Jenkins, G.J. & Ephraum, J.J. (1990). *Climate Change. The IPCC Scientific Assessment. Intergovernmental Panel on Climate Change*, Cambridge University Press, 1990. (http://www.ipcc.ch/publications_and_data/publications_and_data_reports.htm).
The datasets NASA/GISS and MSU-Satellite are taken from the KNMI (http://climexp.knmi.nl).
[23] The last measurement was taken May 30th 2010. This is over three months before the month of September, during which ice volumes are typically at their lowest. The graph reveals a downward trend of 3400 cubic kilometres of ice lost each year. The retreat of surface ice in the arctic sea shows a similar trend. Between 1979 and 2010 the total surface area of the ice decreased with 2.4 percent each decade. Source: National Snow and Ice Data Center, University of Colorado at Boulder (see: http://nsidc.org/arcticseaicenews/2010/060810.html).
[24] See for example Velicogna, I. (2009). 'Increasing Rates of Ice Mass Loss from the Greenland and Antarctic Ice Sheets Revealed by GRACE'. *Geophysical Research Letters.* Vol. 36, L19503, 4pp.
[25] The median is the midpoint of series of measurement data (i.e. not the same as the average). The maps were constructed based on the 'Sea Ice Index' of the National Snow and Ice Data Center of the University of Colorado in Boulder, which is keeping track of satellite images of arctic sea ice since 1979. (see: http://nsidc.org/data/g02135.html and http://nsidc.org/data/seaice_index/archives/image_select.html).
[26] Source top figure: NASA (see: http://earthobservatory.nasa.gov/Features/WorldOfChange/).
Source bottom two figures: IPCC. The original figure also depicts the projected changes for 2020 and 2050, and includes the projected changes under scenario A1B. Source: Meehl, G.A., T.F. Stocker, W.D. Collins, P. Friedlingstein, A.T. Gaye, J.M. Gregory, A. Kitoh, R. Knutti, J.M. Murphy, A. Noda, S.C.B. Raper, I.G. Watterson,

A.J. Weaver & Z.-C. Zhao: 2007: Global Climate Projections. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[27] Source: Hansen, J., S. Makiko, P. Kharecha, D. Beerling, R. Berner, V. Masson-Delmotte, M. Pagani, M. Raymo, D.L. Rover & J.C. Zachos (2008). Target Atmospheric $CO_2$: 'Where Should Humanity Aim?' *The Open Atmospheric Science Journal*. Vol 2, no. 15 pp. 217-231.

[28] Smaller flows of carbon (like forest fires or sedimentation of organic materials on the ocean floor) and smaller reservoirs (like marine life and sediment on the ocean floor) have not been incorporated into this diagram for reasons of clarity. The figures are valid for an atmospheric $CO_2$ concentration of around 380 ppm and are taken from: IPCC (2007), Climate Change 2007: Working Group 1: The Physical Science Basis – see figure 7.3 (http://www.ipcc.ch/publications_and_data/ar4/wg1/en/figure-7-3.html) and table 7.1 (http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch7s7-3-1-3.html#table-7-1).

[29] Source: Lenton, T.M., Held, H., Kriegler, E., Hall, J.W., Lucht, W., Rahmstorf, S. & Schnellnhuber, H.J. (2008). 'Tipping elements in the Earth's climate system'. *PNAS*, vol. 105, no. 6, pp. 1786-1793

[30] The measurements were obtained through analysis of sediments in the Red Sea and coral reefs. The graph is based on figure 2c in: Rohling, E.J., Grant, K., Hemleben, Ch., Siddall, M., Hoogakker, B.A.A., Bolshaw, M. & Kucera, M. (2008). 'High rates of sea-level rise during the last interglacial period'. *Nature Geoscience*, vol. 1, pp. 38-42.

[31] $pCO_2$ is the partial pressure of $CO_2$ gas. Measuring partial pressure is a good method for determining the amount of a certain gas in a mixture of gases (the concentration). PH measurements are

taken from surface waters (0-30 metres deep). Source: Data from measuring station ALOHA. In: Dore, J.J., R. Lukas, D.W. Sadler, M.J. Church & D.M. Karl (2009). 'Physical and biochemical modulation of ocean acidification in the central north Pacific'. *PNAS*, vol. 106, no. 30, pp. 12235-12240.

[32] The scientists show that the probability of heavy rainfall and accompanying floods in England and Wales has increased significantly over the last four decades. They relate this increase in probability to climate change. See Pall, P., Aina, T., Stone, D.A., Scott, P.A., Nozawa, T., Hilberts, A.G.J., Lohmann, D. & Allen, M.R. (2011). 'Anthropogenic greenhouse gas contribution to flood risk in England and Wales in autumn 2000'. Nature 470, 382-385 (February 17th 2011). (http://www.nature.com/nature/journal/v470/n7334/full/nature09762.html)

[33] Predictions for the years 2050 and 2100 according to KNMI G- and W-scenarios. The G-scenario assumes a reduced emission of $CO_2$ and a mild reaction of the climate on the additional greenhouse gases. Scenario W+ assumes a larger emission and a stronger reaction of the climate system. Source: KNMI, 2008 (see http://www.knmi.nl/klimaatscenarios/knmi06/gegevens/index.html).

[34] See: Van den Biesen, P. (2011). *Will Civil Society Take Climate Changers to Court? A Perspective from Dutch Law*. Unpublished manuscript, Universiteit van Maastricht.

[35] See: The World Bank (2010*). Economics of Adaptation to Climate Change. Synthesis Report. The World Bank, Washington D.C.*. climatechange. (http://siteresources.worldbank.org/EXTCC/Resources/EACC_FinalSynthesisReport0803_2010.pdf)

[36] Average temperature in the Netherlands, based on measurements from stations De Bilt, Winsterswijk, Oudenbosch, Gemert and after 1950 also Gemel and Eindhoven. Source: KNMI (see http://climexp.knmi.nl).

[37] Average precipitation at weather station De Bilt. Source: KNMI (see http://climexp.knmi.nl).

[38] The graph is indexed with the year 2000 as the baseline. For the original graph, see the 'Compendium voor de Leefomgeving' (in Dutch)
(http://www.compendiumvoordeleefomgeving.nl/dossiers/nl0065-effecten-vanklimaatverandering-op-de-natuur.html?i=9-55).
For more information on which species are cold-loving and heat-loving see (in Dutch)
http://www.cbs.nl/nl-NL/menu/themas/natuur-milieu/publicaties/artikelen/archief/2007/2007-2289-wm.htm.

[39] Upper limit scenarios for sea level rise in the year 2100. The height of each bar indicates the uncertainty of the projection. Source: Deltacommissie (2008), *Samen werken met water. Een land dat leeft, bouwt aan zijn toekomst. Bevindingen van de Deltacommissie 2008* (see (in Dutch)
http://www.deltacommissie.nl).

[40] This figure was published in 'Hoogtij in de Delta' (high tide in the delta), the inaugural speech of Pier Vellinga at Wageningen Universiteit (October 16th 2008). See (in Dutch)
http://wurtv.wur.nl/p2gplayer/player.aspx?path=aulatv/2008/10/16/1/ for the movie of the inaugural speech and
http://kennisvoorklimaat.klimaatonderzoeknederland.nl/nl/25222685-kvk_Nieuws.html?location=23641140359265,10026100, for the text.

[41] The coastal defense (red lines) are projected on an elevation map of the Netherlands. This figure was published in 'Hoogtij in de Delta' (high tide in the delta), the inaugural speech of Pier Vellinga at Wageningen Universiteit (October 16th 2008). See note 40 for the links.

[42] This figure was published in 'Hoogtij in de Delta' (high tide in the delta), the inaugural speech of Pier Vellinga at Wageningen Universiteit (October 16th 2008). See note 40 for the links.

[43] Source: Pijnappels, M.H.J. & Sedee, A.G.J. (2010). Klimaat als kans. Adaptatie aan klimaatverandering in de ruimtelijke ordening. Stichting, Kennis voor Klimaat, Utrecht. See (in Dutch) http://kennisvoorklimaat.klimaatonderzoeknederland.nl/nl/25223033-Klimaat_als_Kans.html.
[44] The three artist impressions of the playing ground were made by 'DE URBANISTEN'; the photo of the green roof was taken by Rotterdam Climate Proof.
[45] Source: World Bank (2010). See http://data.worldbank.org/indicator/EG.usE.PCAP.KG.OE.
[46] A study conducted by McKinsey for the European Climate Foundation found that the European Union can achieve its target to reduce $CO_2$ emissions by 80 percent using currently available technologies. Energy supply would remain reliable, and operating costs would even be lower than they are in the current supply system. Furthermore, people would not have to make radical changes to their lifestyle. See: ECF (2010). Roadmap 2050: a practical guide to a prosperous, low carbon Europe. (http://www.roadmap2050.eu/attachments/files/Volume1_fullreport_PressPack.pdf.)
[47] The original graph has been modified to show gigatonnes $CO_2$ per year instead of gigatonnes C per year. Source: Stehfest, E., L. Bouwman, D.P. van Vuuren, M.G.J. den Elzen, B. Eickhout & P. Kabat (2009), 'Climate benefits of changing diet'. *Climatic Change*, 95:83-102.
[48] Source: http://tyndall1861.geologist-1011.mobi/Tyndall(1861-Frontispiece).png.
[49] Different isotopes of a chemical element have different weights, because although they have the same number of protons, they have a different number of neutrons. With oxygen, the ratio of $^{16}O$ (more than 99 percent of all oxygen) and $^{18}O$ tells us something about precipitation and evaporation in the past, and hence also about temperatures.

[50] The 6th edition of this book was printed in April 2011. See: Van Dorland, R., Dubelaar-Versluis, W. & Jansen, B. (2011), *De Staat van het Klimaat 2010*, uitgave PCCC, De Bilt/Wageningen.

[51] See: Miskolczi, F.M. (2010), 'The stable stationary value of the Earth's global average atmospheric Planck-weighted greenhouse-gas optical thickness', *Energy & Environment*, vol. 21, no. 4, pp. 243-262.

[52] Deviation of global average temperatures as compared to the average over 1961-1990, obtained through three different measuring methods. NASA/GISS and HadCRUT3 give a combination of the surface temperature of the seas and the temperature of the air at two meters altitude above land. Several satellites equipped with MSU instrumentation measure the average temperature of the bottom eight kilometres of the atmosphere. The values for 2010 are the latest available figures while this book was written (January 2011). Source: KNMI (http://climexp.knmi.nl).

[53] Source: Koopmans, C., B. Tieben, M. van den Berg & D. Willebrands. (2010). *Investeren in een schone toekomst. De kosten en baten van een duurzame energiehuishouding in Nederland*. SEO Economisch Onderzoek, Amsterdam, July 2010.

[54] http://www.telegraph.co.uk/travel/travelnews/7941029/Russian-wildfiresprovoke-Foreign-Office-warning.html.

[55] Source: Van Vuuren, D.P., Hof, A.F. & den Elzen, M.G.J. (2009), Meeting the 2ºC Target. From Climate Objective to Emission Reduction Measures. Planbureau voor de Leefomgeving (pbl), Bilthoven, publ. nr. 500114012. See http://www.rivm.nl/bibliotheek/rapporten/500114012.pdf.

[56] The concentration went up from 315 to 390 parts per million since 1958. The yearly fluctuations (see cadre) is caused by the difference in landmass between the northern and southern hemispheres. There is much more land in the North, which translates into a large uptake of $CO_2$ by vegetation in the summer. This $CO_2$ is reemitted into the atmosphere when the leaves drop in

autumn. Source: measurements taken by NOAA on Mauna Loa (Hawaii). See: www.esrl.noaa.gov/gmd/ccgg/trends/.

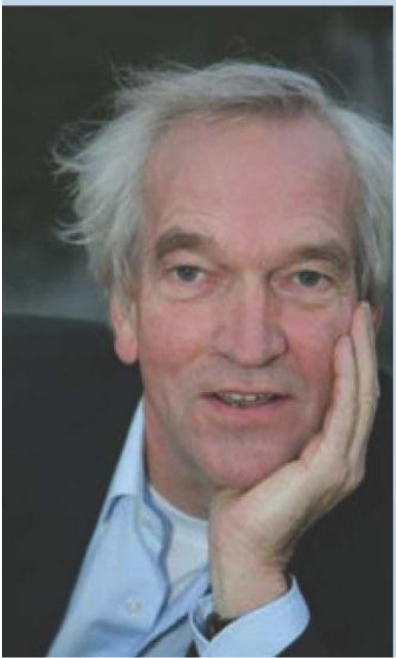
[57] Between 1958 and 2008, the percentage of $CO_2$ that remains in the atmosphere has increased with 0.3 percent annually. Source: Bron: Le Quere, C., Raupach, M.R., Canadell, J.G., Marland, G., Bopp, L., Ciais, P., Conway, T.J., Doney, S.C., Feely, R.A., Foster, P., Friedlingstein, P., Gurney, K., Houghton, R.A., House, J.I., Huntingford, C., Levy, P.E., Lomas, M.R., Majkut, J., Metzl, N., Ometto, J.P., Peters, G.P., Prentice, I.C., Randerson, J.T., Running, S.W., Sarmiento, J.L., Schuster, U., Sitch, S., Takahashi, T., Viovy, N., van der Werf, G.R. & Woodward, F.I. (2009), 'Trends in the Sources and Sinks of Carbon Dioxide', *Nature Geoscience* vol. 2, pp. 831-836.

[58] Reference to the book Oreskes, N. & Conway, E.M. (2010), *Merchants of Doubt. How a Handful of Scientists Obscured the Truth on Issues from Tobacco Smoke to Global Warming*. Bloomsbury Press, New York, p. 355.

Why worry about climate change? After all, a warmer earth may have longer growing seasons. Maybe it's not $CO_2$ but our expanding cities that are the cause of rising temperatures. Maybe it is just solar variability. Could it be that climate scientists have exaggerated?

These are some of the questions Pier Vellinga has asked himself over the course of 30 years of research on climate change and its implications for society.

In this book he systematically discusses all questions surrounding the issue. He makes a link with earlier predictions regarding limits to growth, acid rain and the ozone layer. He makes a clear distinction between what is known for certain, what is less certain and what is pure speculation. This book "On Climate Change" helps to understand and respond to every day questions on climate change in easily accessible language. In two hours you can read everything you need to know about Climate change.



Professor Pier Vellinga (1950), is one of the first scientists in the Netherlands focusing on Climate Change and its societal implications. He was one of the initiators of the Intergovernmental Panel on Climate Change (IPCC) in 1989, and is an international authority on sea level rise and how to adapt to it. He is now (2008-2015) leading the Netherlands national research program "Knowledge for Climate". He also has a professorial chair at the Wageningen Universiteit and at the Vrije Universiteit in Amsterdam.

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