Climate challenge – the safety's off

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Introduction

The world is getting warmer, and this is very probably due to human emissions of greenhouse gases. That is the conclusion of the Intergovernmental Panel on Climate Change (IPCC), which links warming to rising sea levels, shrinking ice and the risk of rapid and unpredictable changes. But, when does man's impact on the climate become dangerous, and what is at stake? Is the EU energy and climate policy a toothless tiger? Is carbon dioxide capture and storage a solution or just a smokescreen? Is the threat to the climate an opportunity for companies?

This book contains articles written by some forty researchers about the physical science basis, about climate impacts, adaptation and vulnerability, and about mitigation of climate change.

Fossil fuels will continue to dominate energy supplies for a long time, and emissions of greenhouse gases will continue to increase. Today's emissions trend is following the very worst-case scenarios. The actual reductions in emissions that are required in order to avoid serious climate change are worryingly far from the reality we have on our planet at present, according to Mattias Lundblad from the Swedish University of Agricultural Sciences.

THE PHYSICAL SCIENCE BASIS

According to the IPCC and Erland Källén at Stockholm University, it is very likely that man's use of fossil fuels is the cause of the majority of warming during the 20th century. The technology exists to limit these emissions, however, and the costs are not too alarming. We do not have that much time to consider the issue, but have to start reducing emissions in earnest very soon in order to avoid ending up in a situation where the warming has gone too far. Erland Källén summarises the IPCC's 2007 assessment report as well as subsequent research up until 2009.

Measurements and modelling are important research methods for a climate scientist. Which is best when it comes to finding out something about the climate in future? Both are useful when we study the climate, but both also have limitations, writes Markku Rummukainen from the Swedish Meteorological and Hydrological Institute (SMHI). Measurements support modelling – and vice versa, so the tools are best used in concert. However, measurements cannot reveal the future to us. With models we can make projections and scenarios for the future – although not perfect ones.

So why should we believe in climate models? Building a climate model entails balancing many different factors – as if on a knife-edge – some that we know well and others where knowledge is incomplete. Clouds are one Achilles heel, and aerosol particles another. There are also probably things that we don't yet know that we don't know. Still, the models provide a good description of the observed climate system. However, we must never forget that a model is only a model, and not the reality. There is always a risk that we may get the right answer for the wrong reason, writes Michael Tjernström, Stockholm University.

There are both natural climate variations and human impact on the climate. There is no contradiction in this, and the research community has long since passed this stage of the discussion, writes Per Holmlund, Stockholm University. However, there is a great deal that we do not know, and the truths on which we rely occasionally rest on fragile foundations. For this reason, climate scientists should take the initiative in the debate more often, and not just answer questions passively and pleasantly. This would be one way of reducing the room to manoeuvre currently enjoyed by climate charlatans, according to Per Holmlund.

The Earth's climate is driven by the sun's radiation. However, the sun is not just a white disc 150 million kilometres away, and the number of sunspots does not give a good picture of the sun's activity. Henrik Lundstedt at the Swedish Institute of Space Physics in Lund paints a more dynamic portrait of an active corona sun with solar flares and solar winds that affect the climate here on Earth in a number of different ways. As long as IPCC researchers draw their conclusions based on the outdated sunspot image of the sun, they cannot say that they know what impact the sun has on the Earth's climate, he writes.

Global emissions of particles have a major impact on the climate – both warming black soot particles and cooling white particles. The contribution of the soot particles to warming is equivalent to just over half of human carbon dioxide emissions. Replacing biofuels that are used for cooking in the tropics with another technology could be one of the most effective methods of reducing climate warming, writes Örjan Gustafsson, Stockholm University. Particles must be included in future climate agreements, and developed countries must understand that they will benefit from co-financing measures in developing countries.

"The climate has varied dramatically in the past, so why should today's situation be unusual? The sun must surely still be more important than man's impact on the climate!" These are two of many claims that Eigil Kaas, University of Copenhagen, sets about answering. He distinguishes between feedbacks and climate change drivers. The magnitude of past climate variations was largely due to feedbacks. The driving factors such as the strength of the sun and fluctuations in the Earth's orbit around the sun only had modest direct impact. Today's trend of rising temperatures is mainly due to human climate drivers.

Is it true, as is often claimed, that science is united around the theory that global warming is man-made? In order to answer this question, we need to specify what is meant both by the theory in question and by scientific consensus. Olle Häggström, Chalmers University of Technology, examines these notions and comes to the conclusion that science is in agreement that, at present, there are no reasonable grounds to believe that the theory is incorrect.

The vast majority of us cannot investigate the status of the climate ourselves, and we all know that scientific forecasts of the future are not always accurate. So why should we believe in climate change? The most important reason is that we can rely on science as a process, writes Sverker Sörlin at the Royal Institute of Technology and Stockholm University.

When this process entails a broad consensus, as now in the climate issue, society has to work on the basis that it is true.

IMPACTS, ADAPTATION AND VULNERABILITY

According to the UN Climate Convention, we must work to prevent dangerous human impact on our climate. But what is “dangerous”? The word is both very precise and troublesomely imprecise. Decisions taken within climate change negotiations and mitigation efforts basically concern what risks we can tolerate and what measures we are prepared to take, writes Markku Rummukainen, SMHI. Our values have a given role in the debate. Science can in turn shed light on the consequences of various courses of action and what is required to achieve the goals laid down, but it cannot provide us with ultimate answers. Regardless of this, we have to make decisions.

Climate change has already affected the distributions and annual cycles of many species, disrupting the natural balance within ecosystems, writes Benjamin Smith, Lund University. Continued changes might affect ecosystem services and biodiversity in ways that we cannot foresee. Poor countries and regions that have the most to lose may suffer the severest changes. Changes already witnessed are sufficient cause for concern. Terrestrial ecosystems currently absorb over a quarter of anthropogenic carbon dioxide emissions, dampening the increase in greenhouse gas concentrations and mitigating climate change. But this favourable ecosystem service could change abruptly or even reverse, the carbon sinks converting into sources and causing climate change to proceed even more rapidly.

Ecosystems are complex – an insight that must govern our handling of the climate challenge. These systems can change rapidly and in such a way that they cannot recover. In addition, the world's various systems in the fields of information, trade, tourism and finance are linked. An event or environmental change in one part of the world can cause problems on a completely different continent, as in World of Warcraft. However, a globalised world can also be seen as our greatest strength, as innovations can spread rapidly across the planet, writes Victor Galaz, Stockholm University.

Atmospheric temperature has risen more rapidly than sea surface temperature. However, marine ecosystems are not only affected by temperature changes, but also by salinity, acidity and ocean mixing. The sea becomes more acidic as carbon dioxide is dissolved, and this makes it more difficult for organisms to use calcium carbonate to form shells or skeletons. Most coral reefs will probably disappear within thirty years. A positive consequence of climate change is that certain fish species will spread northwards as the climate becomes warmer, writes Keith Brander at the Technical University of Denmark.

More heat waves and more droughts, more serious storms and floods – these are consequences of climate change that can entail direct risks and health effects for people. Indirect health effects might include increased problems for individuals with pollen allergies, as well as the increased spread of infectious diseases, both via insects and animals as well as via food and water. Africa will probably be hit the hardest, in the form of droughts, famines and the spread of malaria, write Bertil Forsberg and Anna-Karin Hurtig from Umeå University.

The share of bioenergy in the energy mix should increase in order to reduce emissions of greenhouse gases. At the same time, demand for food and other agricultural commodities is growing, and further competition can arise for limited resources such as land and water. Water stress and scarcity already represent a significant development impediment in many places, and when the climate changes this situation may be exacerbated. It will be necessary to use water more effectively in order to increase the amount of biomass produced and utilised per unit of water. Considerable improvements are possible and demand for bioenergy is opening the door to new opportunities, write Göran Berndes, Chalmers University of Technology, Louise Karlberg, Stockholm University, and Jan Lundqvist, Stockholm International Water Institute.

Increased production of modern biofuels in developing countries can reduce poverty and alleviate the impact on the climate. However, it is necessary to select crops that are adapted to the ecological and social conditions. In Zambia, it has been determined that the bush *Jatropha curcas* is the most suitable crop for the production of biodiesel. Jatropha can also supply a number of other products, while also contributing to reduced deforestation, improved soil and rural development, write Francis X. Johnson, Stockholm Environment Institute, and Thomson Sinkala, University of Zambia.

It is important to consider the effects of today's coastal planning decisions on future generations. Doing nothing will be costly from both a human and financial perspective, write Richard J.T. Klein and Annika E. Nilsson, Stockholm Environment Institute. They use the examples of Bangladesh, the

Arctic and the Netherlands to illustrate their case. But the best way of limiting the long-term costs is to slow down climate change by reducing emissions of greenhouse gases. After all, it is hard to imagine how even a rich country could cope with a rise in sea level of several metres.

Will climate change give rise to conflicts and war? This issue must be examined scientifically and in detail, writes Peter Haldén of the Swedish Defence Research Agency (FOI). He has studied the consequences of moderate climate change in Darfur and the Arctic. His conclusion is that the climate does not give rise to conflicts – people do. However, drought and famine can make the situation worse. Oil that becomes accessible in the Arctic when the ice melts is a ticking climate bomb. If we fail to mitigate climate change, we will be living in an uncertain world by the end of the century.

MITIGATION OF CLIMATE CHANGE

When we try to set emissions targets for carbon dioxide, we have to put up with many uncertainties. It is not certain how much the temperature will increase by when the concentration of greenhouse gases in the atmosphere increases, and it is not certain what effects a global increase in temperature will have, writes Daniel Johansson, Chalmers University of

Technology and University of Gothenburg. Neither is it obvious what should be classed as "dangerous anthropogenic inference with the climate system". If we want to be relatively sure of reaching the EU two-degree target, we have to start reducing emissions drastically right now and continue for the next few decades. There will then be more room for manoeuvre later on.

The EU's goal of allowing the Earth's average temperature to increase by a maximum of two degrees will be possible to achieve by a clear margin as regards carbon dioxide emissions if we switch to an electric society, writes Sven Kullander, Royal Swedish Academy of Sciences. According to studies carried out within the Academy's energy committee, it is estimated that carbon dioxide emissions from fossil energy sources could be reduced from the current figure of 28 billion tonnes per year to 20 billion tonnes by 2050. This should be sufficient to achieve the two-degree target.

Both the EU and the rest of the world have great hopes for the technology whereby carbon dioxide is separated and stored. However, there is reason to have a critical attitude, write Anders Hansson, Linköping University, and Mårten Lind, Royal Institute of Technology. There are many uncertainties and little in the way of experience. The critics describe this technology as a smokescreen created by the energy industry in order to continue burning fossil fuels. They feel that the technology is complicated and expensive and the actual storage process is uncertain. Advocates believe that carbon dioxide can be stored safely and that this can be achieved without excessive costs.

If global climate change is to be addressed seriously, we need to reduce carbon dioxide emissions using all available technologies, including capture and storage of carbon dioxide (CCS). Given the large reserves of fossil fuel that remain to be used, failure of CCS would be a nightmare scenario. However, the outlook of this technology looks bright. In the long term, it will be important to establish a global price for carbon dioxide emissions that is sufficiently high to ensure that CCS and other technologies will be implemented on a large scale, writes Filip Johnsson, Chalmers University of Technology.

Global justice as regards the climate – is this possible? What is most important: for benefits and burdens to be shared equally, or for everyone to participate in climate policy decisions? Or is there a third way? The most important thing is perhaps to discuss what is at stake for people in different parts of the world, writes David Olsson Kronlid, Uppsala University.

The climate issue is a hot topic in top-level politics and international negotiations. What requirements should be stipulated regarding emission reductions? How should the burdens be shared? What principles should apply? Björn-Ola Linnér, Linköping University, and Bo Kjellén, Stockholm Environment Institute, paint a picture of international climate co-operation – from Rio to Copenhagen. If the results from Copenhagen in December 2009 are weak, we will probably have a debate about the Climate Convention. Is the UN route the right one? Is there too much market and too little political control in today's climate work?

Can the Kyoto Protocol's flexible mechanisms save the climate? No, not on their own, writes Lars Zetterberg, IVL Swedish Environmental Research Institute. First, it is necessary for the world's leading nations to make concrete commitments regarding emissions reductions. After that, the flexible mechanisms can help us to achieve the goals at the lowest possible cost. They can be the tools that introduce a global carbon dioxide price, making the climate issue a matter for company boards of directors. There should not be any climate tax-free paradises where dirty industries can hide away.

In the EU, the climate and energy policy is viewed as an instrument that should both resolve the climate threat and reduce the dependency on energy from unstable regions of the world. But how can the EU move from rhetoric to practical action? Society's conflicting aims are not visible in the rhetoric about the EU's climate and energy policy, argues Karin Bäckstrand, Lund University. At present, the EU has neither the regulatory tools nor a democratic mandate to implement a major societal restructuring and transformations of energy systems, transport and consumption patterns for a carbon-efficient future. The power over energy supplies still lies in the hands of the member states.

When Europe lays down goals for the increased use of biofuels, this affects people in low income countries, for example Indonesia, where oil palm plantations are expanding. Even though the EU's intention is for developing countries to have the opportunity to combat poverty by selling biofuels to Europe, it is not certain that it will work like this in practice. At present our European technical solutions are prioritised, without due consideration of the wider environmental and social implications in the countries that produce our biofuel, write Maria Osbeck, Stockholm Environment Institute, and Neil Powell, Stockholm Environment Institute and Swedish University of Agricultural Sciences.

Why have these climate problems arisen in the first place? Social sciences give many, widely varying answers, writes Johan Hedrén, Linköping University. These differences are due in part to which factors are perceived as most important: ideas, economy, technology or politics. There is no scientific consensus on which social theorists are correct. Everyone has to form their own opinion. It is not sufficient to use modern media, which simplify matters far too much. If you want to understand complex issues, social theory has an important role to play.

In order for Swedish companies to be competitive in countries such as India and China, they have to develop technology incorporating environmental performance that exceeds what is currently demanded by Swedish and European legislation, and they have to do this as soon as possible. Companies obviously have to abide by laws and regulations. But should they also accept voluntary responsibility for the climate and the environment? Must they, can they, should they and do they? These questions are investigated by Pontus Cerin, Umeå School of Business, and Tommy Lundgren, Umeå School of Business and Swedish University of Agricultural Sciences.

The global climate issue and the global business climate have major similarities, but also major differences. The climate issue is collective in nature, whereas the business world is driven by self-interest and ideas of growth, writes Johan Sandström, Örebro University. Growth in the economy means "growth" in climate impact. The challenge is to find solutions that benefit both the climate and companies. In the absence of global institutions that have the power to persuade global companies to accept more responsibility for the climate issue, clear signals are required from strong global citizens.

Birgitta Johansson, editor

Birgitta Johansson is a scientific journalist and senior information officer at the Swedish Research Council Formas.

Global greenhouse gas emissions

The average temperature of the Earth has risen by approximately 0.8 degrees Celsius since the end of the 19th century. According to the UN's climate panel, the IPCC, the majority of this increase is due to human emissions of greenhouse gases.

The greenhouse gases that are regulated by the Kyoto Protocol are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O, laughing gas) and various fluorinated gases. As these gases have varying degrees of impact on the greenhouse effect, the emissions are often converted using their global warming potential (GWP) so as to be comparable with the greenhouse effect of carbon dioxide. This means that all emissions of greenhouse gases are presented as carbon dioxide equivalents.

Carbon dioxide itself is responsible for almost 77 per cent of the combined emissions (figure 1). The emissions of carbon dioxide are primarily caused by the burning of fossil fuels and by deforestation. Nitrous oxide comes from sources such as agriculture, waste and transport. Methane derives primarily from ruminant livestock, rice cultivation and waste. However, the gas is also released from the ground, for example when permafrost melts, a process that could accelerate in a warmer climate. Fluorinated greenhouse gases are formed in industrial processes.

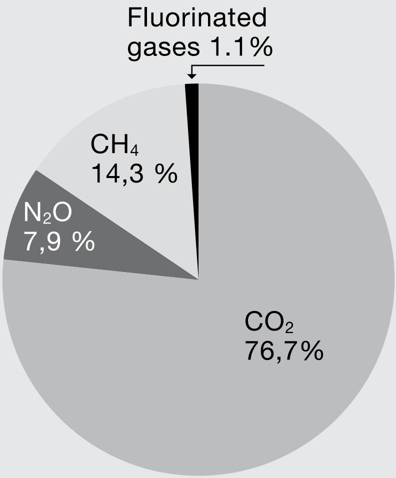


Figure 1. Distribution of emissions of greenhouse gases included in the Kyoto Protocol. Carbon dioxide is responsible for almost 77 per cent of the combined emissions, when all the emissions have been converted to carbon dioxide equivalents. (Source: IPCC 2007)

Greenhouse gases increasing in the atmosphere

Since the industrial revolution in the 19th century, the level of greenhouse gases in the atmosphere has increased dramatically. The level of carbon dioxide has increased by more than 35 per cent, from the pre-industrial level of around 280 parts per million (ppm) to the current level of approximately 385 ppm (figure 2). This increase is primarily due to increasing emissions from the burning of fossil fuels, which initially primarily comprised coal. In the 1960s, oil overtook coal as the most common fuel. The felling of forests has also contributed to increasing the atmospheric concentration of carbon dioxide.

Since pre-industrial times, many of the Earth's forest areas have been felled, and the loss of forests is now responsible for around 20 per cent of the emissions of carbon dioxide to the atmosphere.

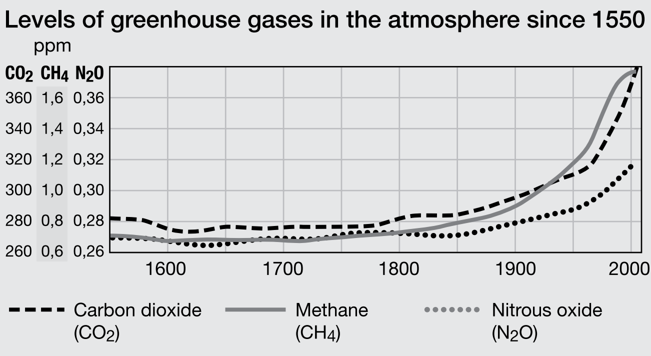


Figure 2. Atmospheric levels of the greenhouse gases carbon dioxide and methane have increased dramatically since the 19th century, particularly methane. The greenhouse gas nitrous oxide (laughing gas) has also increased, although not as much. (Source: IPCC 2007)

Between 1970 and 2004, global emissions of greenhouse gases increased by around 70 per cent, from just below 30 billion tonnes to almost 50 billion tonnes of carbon dioxide equivalents per year. Emissions of carbon dioxide increased by around 80 per cent during the same period. Carbon dioxide emissions have generally followed economic developments in the world, and have consequently increased during economic boom periods and decreased during recessions and other crises. For example, emissions of carbon dioxide fell noticeably during the Second World War, when access to oil was restricted.

Several significant increases in the price of oil during the 1970s, the economic crisis in the East following the fall of Communism at the end of the 1980s, and a temporary weakening in China's economic development at the end of the 1990s are other examples of events that have temporarily affected the emissions trend in certain regions.

Up until now, the industrialised nations have been responsible for the majority of carbon dioxide emissions, although the strongest increase in emissions is now taking place in developing countries with rapidly growing economies (figure 3). In total, global carbon dioxide emissions have increased five-fold since the Second World War.

Contributions from various sectors

The energy sector is responsible for the largest proportion of global emissions of greenhouse gases,

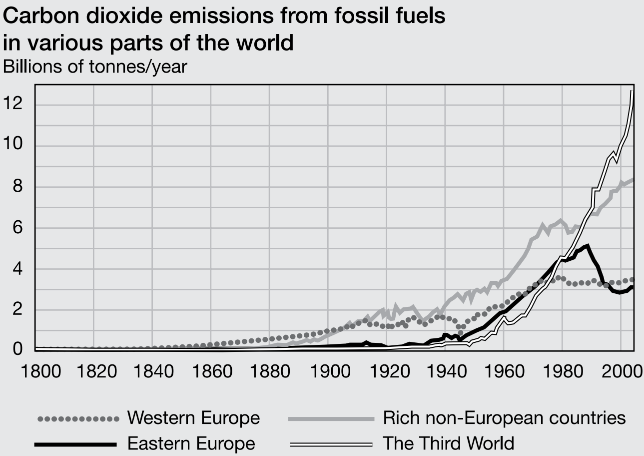


Figure 3. Carbon dioxide emissions from fossil fuels have varied with economic fluctuations, world wars and economic crises. The strongest increase in carbon dioxide emissions is now taking place in the rapidly growing economies of the Third World, such as China and India. (Source: Carbon Dioxide Information Centre, Oak Ridge)

making up more than a quarter in 2004 (figure 4). After this come industry, forestry and agriculture. The transport sector, which is one of the most significant emission sectors in Sweden (just over 30 per cent), is only responsible for a small proportion of total greenhouse gas emissions globally (13 per cent in 2004).

The largest increase between 1970 and 2004 (figure 5) came from the energy sector, which increased its emissions by 145 per cent, and the transport sector,

Greenhouse gases globally from different sectors (2004)

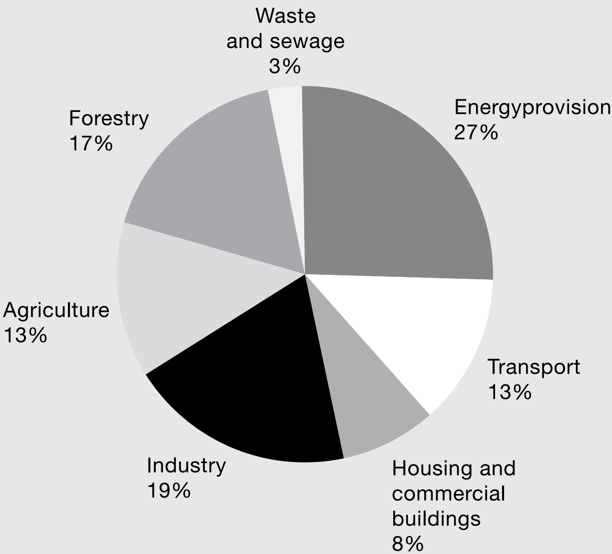


Figure 4. In 2004, the energy sector was responsible for more than a quarter of global emissions of greenhouse gases. Transport is responsible for a fairly small proportion from a global perspective. (Source: IPCC 2007)

which increased its emissions by 120 per cent. The land use sector increased emissions by 40 per cent. This also includes emissions from deforestation, where uncertainty as regards the data means that the trend is considerably less certain than in other sectors. The global rate of deforestation was slightly lower during the period 2000–2005 compared to the period 1990–2000.

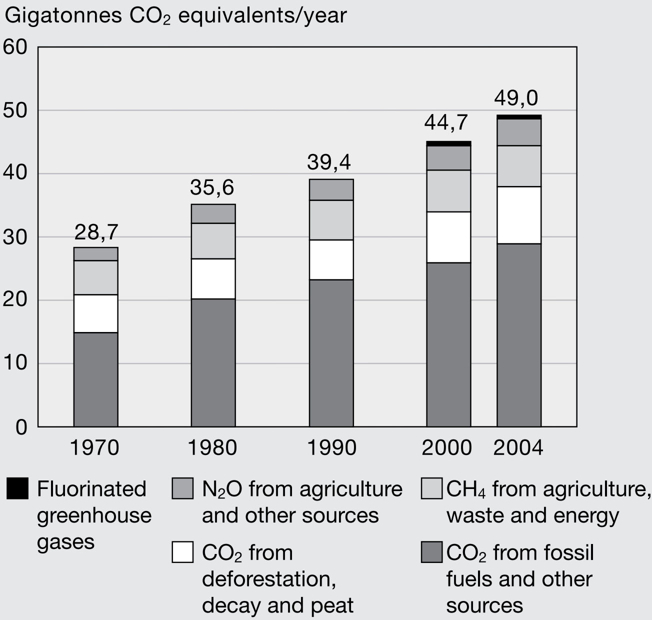


Figure 5. Emissions of greenhouse gases from various sectors have increased steadily since 1970, and are continuing to increase. (Source: IPCC 2007)

The global energy intensity (the relationship between total energy consumption and GDP) has fallen by 33 per cent between 1970 and 2004. However, this has had a smaller effect on global emissions than the combined impact of the global increase in income (77 per cent) and the global population increase (69 per cent), which are the driving factors behind the increasing energy-related carbon dioxide emissions.

Increase in emissions continuing

According to a study carried out by the Dutch environment agency, using data for 2007 based on fossil fuel consumption and cement production, global emissions are continuing to rise. Between 2006 and 2007, emissions increased by 3.1 per cent. This increase is primarily due to fossil fuel consumption, even though the increase in global energy production was slightly smaller between 2006 and 2007 compared to previously. The primary factors affecting energy consumption are the higher oil prices in recent years and the weather conditions during the year.

This compilation also shows that China was responsible for two-thirds of this increase, and that it has now passed the USA as the country that emits the most carbon dioxide.

China is responsible for 24 per cent of global emissions, followed by the USA (22 per cent), the EU (12 per cent), India (8 per cent) and Russia (6 per cent). Calculated per capita, however, China is still far behind the USA, which is responsible by a clear margin for the most carbon dioxide emissions per person. US inhabitants emit an average of 19.4 tonnes of carbon dioxide per year, whereas the average Chinese person emits 5.1 tonnes per year. The corresponding figures are 8.6 tonnes for the EU, 1.8 tonnes for India and 11.8 tonnes for Russia.

The IPCC anticipates increased emissions

In the scenarios that have been produced to date within the IPCC, no particular climate measures have been assumed. This means that none of the scenarios explicitly include any effect from the UN Climate Convention or its Kyoto Protocol when it comes to the continued emissions trend. It is assumed that fossil fuels will retain their dominant position for many years to come.

In its scenarios, the IPCC anticipates that carbon dioxide emissions from energy consumption between 2000 and 2030 will increase by between 45 and 110 per cent. Between 50 and 75 per cent of this increase is expected to come from regions other than developed countries and countries with transitional economies. According to the scenarios, however, the average carbon dioxide emissions per capita from these other regions will, up until 2030, remain significantly lower (2.8–5.1 tonnes of carbon dioxide per person per year) than the emissions from developed countries and countries with transitional economies (9.6–15.1 tonnes of carbon dioxide per person per year).

The challenge awaits us

These scenarios for the future emissions trend are the ones used most often in global climate models in order to calculate the future development of the climate. As the scenarios do not encompass any specific climate measures, the emissions reductions that are assumed to be necessary to avoid serious climate change and that are now being discussed in the international climate negotiations are a long way from the trend that is predicted in the scenarios. Today's emissions trend is following the scenarios that include the greatest increase in emissions and that produce the most serious consequences. The need for rapid, powerful measures to reduce emissions is therefore very great.

It is obvious that in future we will be faced with a major challenge as regards reducing emissions, and a heavy responsibility now rests on the shoulders of the world's decision-makers.

This section has been written by Mattias Lundblad, who is employed as an investigator at the Department of Soil and Environment, Swedish University of Agricultural Sciences (SLU). In recent years, Mattias has worked on climate issues at the Swedish Environmental Protection Agency. At SLU he is now involved in reporting greenhouse gas flows from the land use sector and data for the international climate negotiations.

The UN's climate panel, the IPCC

The UN's climate panel, the IPCC (Intergovernmental Panel on Climate Change), was established in 1988 by the UN's Environmental Programme (UNEP) and the World Meteorological Organization (WMO). More than 190 countries participate in the work of the panel, which is based on evaluating and summarising scientifically based knowledge about potential human impacts on the climate and its consequences.

The work is conducted in three working groups, which focus on 1) the physical climate system and its changes, 2) the consequences of climate change for nature and society and the opportunities for adaptation, and 3) methods for limiting anthropogenic emissions.

Many scientists were actively involved in the work on the fourth assessment report published in 2007 (Climate Change 2007, IPCC Fourth Assessment Report or AR4). In total, more than 800 scientists from many different research disciplines took part. Examples of research areas include meteorology, oceanography, physical geography, glaciology, geochemistry, climate history, hydrology, biology, ecosystem analysis, economics and energy systems.

The IPCC reports are based on the existing reviewed scientific literature. The fourth report was based on research published up to and including 2006. In other words, the IPCC does not conduct any research of its own and does not contribute to any measurement programmes. The assessment of which measures could potentially be implemented and which consequences society is prepared to accept is a political issue, and the IPCC does not adopt a stance in this respect. The IPCC reports only provide a basis for decision-making but do not give any recommendations as regards measures. Instead they describe the consequences of various actions, from both a scientific and a social science perspective. Each report is summarised for decision-makers. The reports that were published in 2007 had been examined by 2,500 experts. In April 2009, the Swedish researchers Erland Källén and Markku Rummukainen presented the very latest climate research on the physical climate system in the report "New climate science 2006–2009". The next IPCC report will be published in 2013–2014.

The IPCC's assessments are used as a scientific basis for the negotiations that are conducted within the framework of the UN Climate Convention. The fourth report came to the conclusion that it is very probable (90–99 per cent) that human emissions of greenhouse gases explain the majority of the warming we experienced during the latter half of the 20th century.

Recommended reading

- The IPCC:s Assessment Reports are available via www.ipcc.ch, including the full reports, their technical summaries and the summaries for policy-makers (SPM). The AR4 Synthesis Report pulls together the main findings of the three working group reports:
  – *Climate Change 2007: Synthesis Report.* Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC 2007 (www.ipcc.ch).

THE PHYSICAL SCIENCE BASIS

The Earth's climate according to the IPCC

It is very likely that human consumption of fossil fuels is the cause behind most of the warming that took place during the 20th century. The technology exists to limit these emissions, however, and the costs are not too alarming. We do not have that much time to consider the issue, but have to start reducing emissions in earnest very soon in order to avoid ending up in a situation where the warming has gone too far. Erland Källén summarises the IPCC's Assessment Report from 2007 and subsequent research up until 2009.

Erland Källén, Department of Meteorology,
Stockholm University.

The Earth's climate has become warmer. During the 20th century, the global average temperature on the Earth's surface increased by 0.7–0.8 degrees Celsius (figure 1). This increase is not uniform; the rising trend is clear at the beginning and end of the 20th century, whereas in the middle of the century there was a plateau with an insignificant temperature trend. The warmest year in the 20th century was 1998, after which the temperature has only risen weakly. Over the past five years (2004–2008), the global average temperature has actually fallen slightly.

At the same time as the world has become warmer, a number of effects of this warming have been observed. The sea ice in the Arctic is retreating, particularly during the summer months. Mountain glaciers are melting. Snow cover and permafrost regions are shrinking. This warming is unique in a historical perspective. Over the past 1,300 years (the period for which we have sufficiently good data), there is probably no corresponding period with equally dramatic warming.

Man a very probable cause

So what happened during the 20th century that caused the climate to become warmer? The most important cause is the increase in the level of greenhouse gases (GHG) in the atmosphere. In line with the

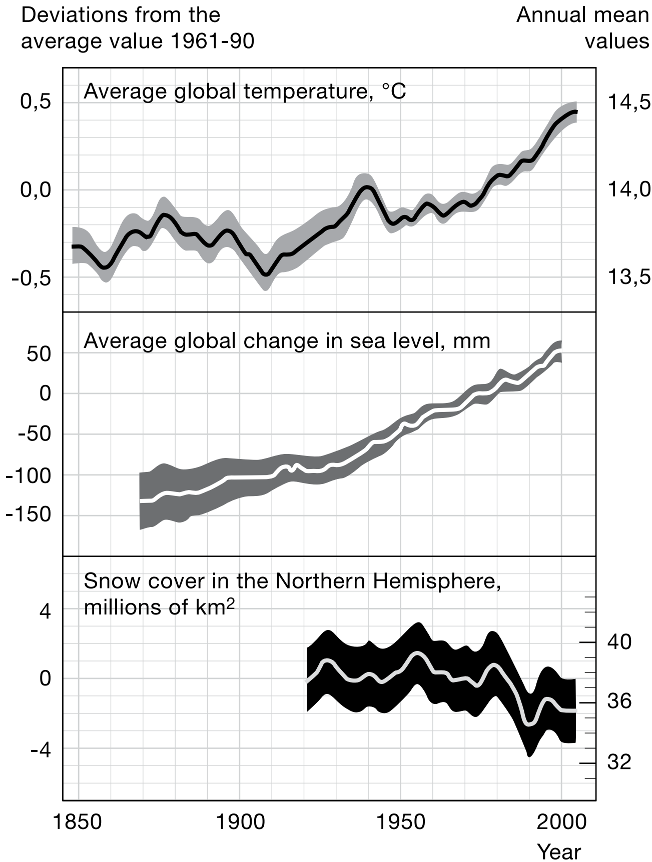


Figure 1. The Earth's average temperature has increased steadily over the past 150 years. The sea level has risen, and snow-covered areas in the Northern Hemisphere have shrunk.

advance of industrialism and our use of fossil fuels (coal, gas and oil), the concentration of carbon dioxide in the atmosphere has increased steadily, and now stands at around 385 ppm; in the middle of the 19th century the level was around 280 ppm. Carbon dioxide is an important greenhouse gas, and the increase in the concentration of carbon dioxide is leading to warming at the Earth's surface. At the same time, the number of particles in the atmosphere has increased in conjunction with the use of fossil fuels. Increased particle levels result in a cooling of the climate, as the particles reflect the sun's rays and make the clouds slightly whiter. Changes in the sun's radiation may also have affected the climate during the 20th century, both in the form of changes in the strength of the sun's radiation, and possibly through changes in the sun's magnetic field. The sun has a decisive influence on the Earth's climate, of course, but the observed changes in radiation are so small that they can scarcely explain any significant proportion of the observed temperature variations.

With the aid of climate models, climate scientists have been able to demonstrate a clear causal link between changes in the temperature and the increase in various greenhouse gases, particle levels and natural climate fluctuations. During the latter part of the 20th century, there is a clear link between the increase in the level of carbon dioxide and the temperature. The 2007 IPCC report establishes that

"Most of the observed increase in global average temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic GHG concentrations". This is a very powerful assertion. In previous IPCC reports, it has only been described as *possible* or *likely* that man is behind the observed warming. This assertion is now made with a considerable level of certainty.

The IPCC's definition of likelihood can be seen from the table below. The fact that it is "very likely" that the warming is due to humans means that nine out of ten attempts to explain the increase in temperature without taking the increase in greenhouse gas levels into account have failed. Attempts in this context refer to the results of calculation models with various

This table presents the IPCC's definition of the likelihood that man is responsible for the majority of the warming since the middle of the 20th century.

Term	Likelihood that man is responsible for the warming
Virtually certain	>99 % likelihood
Very likely	90–99 %
Likely	66–90 %
As likely as not	33–66 %
Unlikely	10–33 %
Very unlikely	1–10 %
Exceptionally unlikely	<1 %

starting points and variations in model parameters. However, if the increase in greenhouse gases is included in the calculations, the results correspond with the actual temperature trend in nine out of ten cases.

Natural climate fluctuations

Even though the majority of the climate changes we are witnessing today are caused by man, there are also natural factors that affect the climate. Historically, natural climate fluctuations are responsible for a significant proportion of climate variations. One example of a natural climate fluctuation is the El Niño phenomenon. In the Pacific region, a redistribution of heat between the sea and the atmosphere takes place at regular intervals, causing temperature and precipitation patterns to change dramatically in particular years. The most powerful El Niño event we know about took place during 1997 and 1998. At this time, the sea surface temperature increased over a large area of the Pacific Ocean. At the same time, precipitation decreased over Indonesia and northern Australia, while increasing around the Equator over the Pacific Ocean. The area that was warmed up was so large that the global average temperature was also clearly affected. 1998 was the warmest year in the whole of the 20th century, and this temperature peak is largely due to El Niño. The temperature fell again in 1999 as El Niño subsided. In recent years, the opposite of El Niño, La Niña, has dominated the circulation pattern over the Pacific Ocean, and this has contributed to the slight fall in the global average temperature.

Another example of natural climate fluctuations are the temperature changes that arise due to volcanic eruptions. Powerful eruptions can discharge a large volume of small particles high up in the atmosphere. These particles, which can remain there for several years, reflect the sun's rays back into space and have a cooling effect on the climate. Over the past forty years, several volcanic eruptions have occurred that have noticeably affected the average global temperature. One example is Pinatubo at the start of the 1990s, which had a cooling effect on the global average temperature for several years.

Changes in the sun's radiation also affect the climate, but over the period of approximately 35 years during which accurate measurements of the sun's radiation have been taken, we have not observed any change that could affect the climate noticeably. Changes in the sun's insolation have produced a clear yet very limited warming effect during the period that man's impact on the climate has grown. The IPCC also discusses other possible mechanisms that can potentially explain climate warming, such as changes in the sun's magnetic field, cosmic radiation and cloud formation. The conclusion is that these factors have probably not affected the climate's development during the 20th century to any great extent. A possible link between variations in the global average temperature and the sunspot cycle has long been discussed, and some scientists have found links between these two phenomena, although they have not succeeded in providing any explanation that is well-founded from a physical perspective. Researchers have recently observed that the global average temperature fluctuates by about 0.2 degrees Celsius between the maximum and minimum points of the sunspot cycle. However, no significant increase in the sun's insolation has been observed in recent decades.

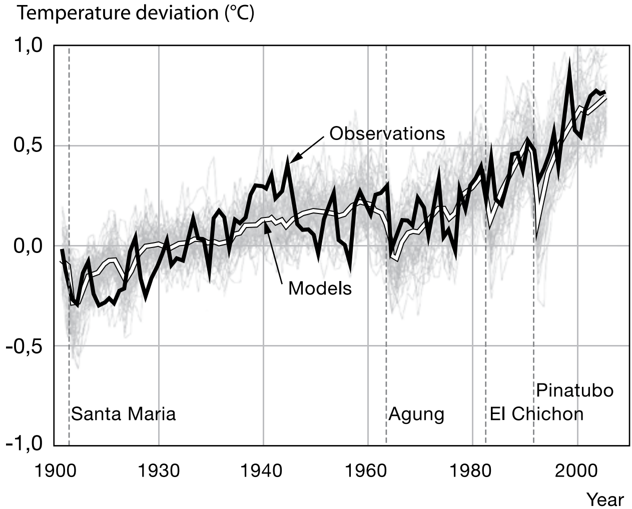
Evidence for man's impact on the climate

What proportion of the warming during the 20th century is caused by the increase in carbon dioxide, and what proportion can be explained by natural climate changes? With the aid of climate models, we can carry out controlled experiments that are impossible to perform with the real Earth's climate. For example, we can assume that the level of carbon dioxide has been constant through the 20th century, but permit volcanic eruptions, changes in solar radiation and natural climate fluctuations. We then obtain a picture as depicted in the lower diagram in figure 2 on next page, where observed temperatures (black line) do not correspond particularly well with temperatures in the model (white line) over the latter part of the 20th century. The warming trend at the start of the 20th century is captured in a way that resembles the trend observed in the upper diagram, but the warming towards the end of the century looks completely different.

If we instead include an increase in the concentration of carbon dioxide in the atmosphere alongside other effects linked to human activities, we obtain the results depicted in the upper diagram. Now the simulation results are similar to the observed temperature variations and the warming trend towards the end of the 20th century is well captured.

A consistent trend in both diagrams is a certain amount of warming at the start of the 20th century, but from the middle of the century onwards, the Earth's climate ought to have become cooler if natural climate fluctuations were the only factor behind the temperature changes. In other words, the observations do not correspond with the simulations during the latter half of the 20th century if only natural climate variability is taken into account. Major volcanic eruptions towards the end of the 20th century

Both natural and anthropogenic factors affecting the climate



Only natural factors affecting the climate

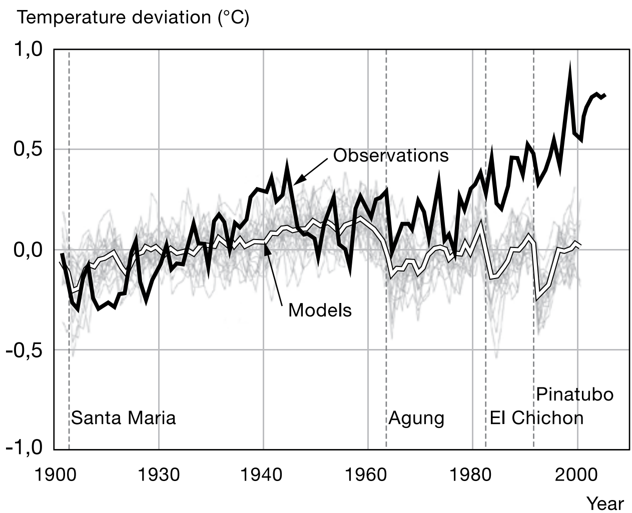


Figure 2. In the upper diagram, climate models have been exposed to both natural climate factors and those factors caused by man. The model's results correspond very closely with the observed temperature. This is not the case in the lower diagram, where the models have only been exposed to natural factors. (Temperature deviation refers to the deviation from the average value during the period 1960–1990.)

have also been indicated in the figure; we can see a clear cooling effect after each eruption.

The simulations that have been carried out with both human impact and natural variations produce results that correspond much more closely with the observations than the simulations that have only taken natural climate variations into consideration. As a result, we can say that it is very likely that the increase in the carbon dioxide concentration in the atmosphere has caused the majority of the climate warming observed at the end of the 20th century. This does not preclude the possibility that some of the warming may also be due to natural variations, but it is unlikely that natural variations alone can explain the warming we have witnessed.

Scenarios for the climate of the future

A continued increase in the concentration of carbon dioxide in the atmosphere will, in all likelihood, result in continued warming. Carbon dioxide remains in the atmosphere for a very long time. Some of the carbon dioxide that has been produced since the 19th century from the burning of coal, oil and gas will remain in the atmosphere for hundreds of years to come. Even if we were to stop using fossil fuels immediately, the level of carbon dioxide would only revert slowly to the levels present prior to the industrial revolution. The continued use of fossil fuels will therefore lead unavoidably to a continued increase in the level of carbon dioxide in the atmosphere.

The rate at which the carbon dioxide concentration will increase depends on how people act. If we succeed in halting a continued increase in emissions and gradually also start reducing them, we can hope that the concentration of carbon dioxide in the atmosphere will stabilise at a level that restricts global warming. However, continued warming is, in all likelihood, unavoidable. With the aid of climate models, we can calculate the extent of this warming using various scenarios for carbon dioxide emissions. Admittedly these calculations include uncertainties, both due to uncertainties regarding emissions levels and due to uncertainties in the climate model calculations of e.g. temperature, humidity, clouds and wind.

Figure 3 shows the results of calculations of the future temperature climate. The top graph illustrates what happens if emissions of carbon dioxide continue to

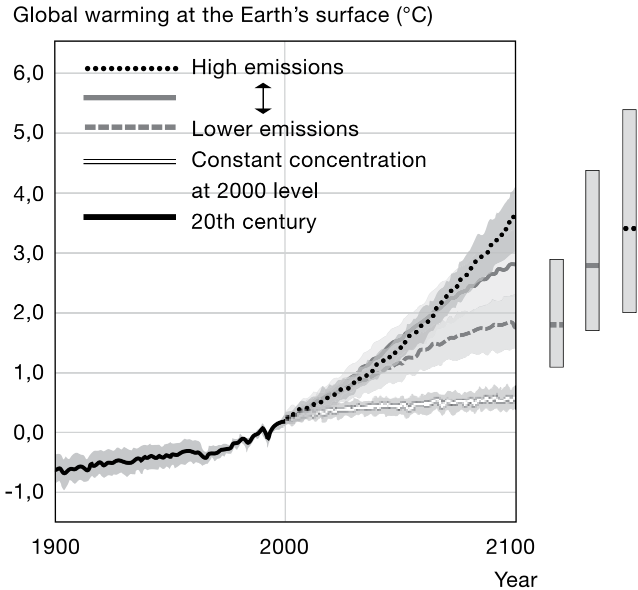


Figure 3. Various scenarios for the future global average temperature based on various levels of carbon dioxide emissions. The bars to the right show the uncertainty range.

increase at the same rate as to date. In this scenario, the global average temperature could increase by around four degrees over the next hundred years. This increase is as large as the temperature difference between today's climate and that at the end of the last Ice Age, more than ten thousand years ago! The figure also shows the results from simulations where we assume that emissions will gradually be restricted and that the carbon dioxide level will stabilise at a level that produces global warming of around two degrees over the next hundred years. The warming is then more limited, although it is still more than double that witnessed over the past hundred years. A warming of four degrees is equivalent to a three-fold increase in carbon dioxide concentrations compared to the starting point in the middle of the 19th century, while a warming of around two degrees corresponds to a doubling of the carbon dioxide concentration.

Consequences of warming

The warming is not distributed evenly across the planet. The Arctic region is warming up more than twice as much as the rest of the world, and land areas are warming up significantly more than sea areas. The Arctic warming is connected to a continued melting of sea-ice in the region, while the sea warms more slowly than land due to its thermal inertia. If emissions of carbon dioxide continue to increase at the same rate as today over the next hundred years, the Arctic will probably be almost free of ice during the summer months. In a global perspective, sea levels could rise by around half a metre. The rising sea level is due partly to the thermal expansion of the sea water, and partly to the melting of inland ice.

For Sweden, such a warming scenario would entail Stockholm having the same temperature climate as

Paris enjoys today. There would be higher levels of precipitation, particularly in the west and north, and the snow season would be considerably shorter in the central part of the country. Parts of the Mediterranean region would have a desert-like climate, while other coastal areas would be affected by rising sea levels. Bangladesh, where the majority of the population live in a river delta at close to sea level, would be largely flooded. A small part of the region would be permanently below sea level, while a larger area would be at risk of being flooded during periods with high water levels. The risk of flooding is so great that considerable parts of the region would no longer be habitable.

Even though there would be significant warming in the industrialised regions of the world, these countries have a greater potential to adapt to climate change than developing countries. Large parts of the Earth's population are already living under marginal conditions; global warming would make their situation considerably worse. Increased amounts of precipitation, more extensive dry periods and continued melting of mountain glaciers will lead to very difficult conditions. Above all, access to water and the spread of diseases have been identified as serious threats in conjunction with continued warming.

If the Earth's average temperature rises by more than two degrees compared to the temperature in the middle of the 19th century, some studies indicate that the effects would be very serious, particularly in developing countries. For this reason, two degrees has sometimes been used as a critical temperature increase level. We should limit greenhouse gas emissions so that this level is not exceeded.

What can we do?

So what level of greenhouse gas concentrations can we permit in the future? If the temperature increase is to be restricted to two degrees, the level of carbon dioxide in the atmosphere must not exceed around 450 ppm. In order to achieve a goal of 450 ppm, it has been calculated that emissions of greenhouse gases have to start falling very soon (within five to ten years) and decrease by around 50 per cent by 2050. At the end of this century (in 2100), emissions should be close to zero.

Is such a drastic reduction in emissions realistic? Yes. The IPCC report demonstrates how such reductions can be achieved and what this will cost. The development of new technology is decisive for reducing emissions. The largest single source of emissions today is energy production. Renewable energy sources (hydroelectric power, biofuels, wind power, etc.), energy efficiency, nuclear power and carbon dioxide capture and storage provide opportunities in both the short and the long term to reduce greenhouse gas emissions. In the longer term, solar energy and perhaps fusion energy could be possible alternatives. Reducing the world's emissions of greenhouse gases would entail comprehensive changes in industry, society and lifestyle.

Will we manage this? Yes, we have to. The higher the level of warming, the greater the risks. Economists have calculated that while the changeover in energy will admittedly have a cost, it will correspond to no more than a few per cent reduction in gross national product over the next hundred years. A large proportion can be achieved through savings, which entails a negative cost. The changeover of the energy production system is expensive, but not so expensive that it cannot be achieved. Financial incentives have to be created that result in reduced emissions. A decisive factor here is the cost of coal; today's coal prices are fairly low. In order to achieve emissions reductions that will result in the restriction of the carbon dioxide concentration to around 450 ppm, a coal price is required that corresponds to SEK 0.15–0.35 per kg of carbon dioxide. By way of comparison, the carbon dioxide tax in Sweden is currently SEK 0.90 per kg of carbon dioxide. (1 SEK is roughly 0.1 euro.)

Serious problem

The climate problem is serious. A large proportion of the warming that has taken place during the 20th century is very probably due to man's use of fossil fuels. This warming will continue; how great it will be and what stresses are placed on the Earth's population depend on how well we succeed in limiting emissions of greenhouse gases in the future. The problem is not insurmountable. Technology and methods exist to limit these emissions, and the costs are not too alarming. But we have to start reducing emissions in earnest fairly soon in order to avoid ending up in a situation where the warming has gone too far and large sections of the Earth's population are at risk of being seriously affected by the changes in the climate.

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More about the climate system

The Earth's temperature is determined by a balance between incoming radiation from the sun and outgoing thermal radiation into space. Higher temperatures on Earth lead to increased thermal radiation. As a result of the atmosphere's greenhouse effect, a large proportion of the thermal radiation from the Earth's surface is trapped in the lower segments of the atmosphere. As a result, it becomes warmer at the Earth's surface than it would have been without the greenhouse effect.

The greenhouse effect is affected by changes in the concentrations of greenhouse gases in the atmosphere. If carbon dioxide increases, for example, more thermal radiation is trapped and the temperature at the Earth's surface rises. A warming of the lower parts of the atmosphere also affects the amount of water vapour and cloud formation, which in turn further alters the radiation balance at ground level. An increase in temperature results in an increased amount of water vapour (increased evaporation from the seas and oceans, etc.) as warmer air can hold more water vapour, and this further enhances the warming at the Earth's surface. Water vapour is namely the most important greenhouse gas.

The inertia of the climate system is governed by the oceans. An imbalance between outgoing thermal radiation and incoming solar radiation at the surface of the sea slowly affects the ocean's temperature. It takes hundreds of years to achieve radiation balance over the sea following an increase in greenhouse gas concentrations. This is due to the relatively slow exchange of the water masses closest to the surface and in the deep parts of the world's oceans.

Clouds

Clouds consist of water droplets and ice crystals that are formed when water vapour condenses. Clouds are normally formed when the air rises; the rising air cools and when a critical temperature is reached, the air can no longer hold all the water vapour, which is partially converted to droplets or ice crystals. The altitude at which this takes place is dependent on the temperature of the air and the concentration of water vapour.

Changes in cloudiness resulting from changes in the climate system's thermal and radiation balance are complex. Depending on how cloudiness changes, the effects on the radiation balance can vary:

- The clouds affect incoming solar radiation by reflecting the radiation. More clouds lead to increased reflection and hence cooling, while fewer clouds have the opposite effect. An increase or decrease in clouds in the lower part of the troposphere, at an altitude of 1–2 kilometres, is particularly effective.

- Increased cloudiness also results in an increase in the clouds' contribution to the greenhouse effect, which produces warming at the Earth's surface. Increased cloudiness at higher levels of the troposphere, at an altitude of 5–12 kilometres, results in warming at the Earth's surface.

These opposite effects of increased or decreased cloudiness partially cancel each other out. Even though the net effect is small viewed in relation to the overall radiation effect of the clouds, it is still significant. The way in which cloudiness changes in the event of an increased greenhouse effect is determined by a complex interplay between changes in evaporation, temperature changes, changes in ice clouds and water droplet clouds, as well as changes in the atmosphere's circulation patterns. Even though a general warming will lead to an increased concentration of water vapour in the air, it does not necessarily mean that more cloud will be formed. Model calculations and observations show that, on average, around half the globe is covered with cloud, while the remainder is clear air or only partially cloudy. No clear trends of global cloudiness have been discerned from cloud observations over the past fifty years. Projections of future climate change cannot predict any uniform cloudiness trend either.

Albedo

Changes in cloudiness are the single largest area of uncertainty in our understanding of the climate system's sensitivity to changes in the radiation balance. This is followed by changes in the overall reflection of solar radiation, which is known as albedo. The clouds' albedo is dependent on their structure and on whether they are made up of large or small water droplets or are dominated by ice crystals. Clouds comprising many small water droplets have a greater reflecting capacity than clouds comprising a smaller number of large droplets. Ice clouds generally reflect a smaller proportion of solar radiation than water droplet clouds. High clouds contain most ice crystals, while low clouds are richer in water droplets. Low clouds therefore reflect solar radiation most effectively. In polluted areas (parts of North America, Europe and Southeast Asia), clouds generally contain more small droplets and therefore reflect more of the solar radiation. This results in cooling that partially compensates for the greenhouse gas warming on a regional scale.

The effect of air pollutants on the radiation balance and cloud formation has attracted much attention in recent years. For example, it has been discovered that certain air pollutants in the form of small, brown particles can have a warming effect. Over parts of Southeast Asia, this type of warming can be of the same magnitude locally as the increased greenhouse effect. Air polluting particles over other areas can instead have a cooling effect, both through the direct effect on solar radiation (reflection) and indirectly by affecting the clouds' albedo.

In addition to cloudiness, the albedo is also affected by the extent of ice and the properties of the land surface. More ice produces greater reflection of solar radiation and hence cooling. Light-coloured land areas (glaciers, snow cover, deserts and cultivated areas) reflect more sunlight than dark areas (forests, lakes). As the ice cover decreases the warmer the climate becomes, this represents a positive feedback mechanism in the climate system.

Ice

The Earth's largest inland ice areas are in Greenland and the Antarctic. If the Greenland ice were to melt completely, the world's sea level would rise by around seven metres. The Greenland ice could melt if the global warming were to be in the region of two to four degrees above the pre-industrial level for several thousands of years. Sea ice is primarily found in the Arctic Basin and around Antarctica. The extent of the sea ice varies considerably between winter and summer, particularly in the Arctic region.

Over the past 50 years, there has been a marked reduction in the Arctic sea ice, in particular during the summer months. This reduction is clearly linked to global warming, which is particularly strong in the Arctic. No corresponding decrease in sea ice has been observed in the Antarctic. The rate of warming is also slower in the Southern Hemisphere, as it mostly comprises sea, which warms up more slowly than land areas. It has been possible to demonstrate clear warming over parts of the Antarctic continent, whereas other parts have become colder over the past 50 years. This warming can be linked to a change in the flow patterns over the Southern Hemisphere, which in turn can be associated with global warming and the thinning of the ozone layer over the Antarctic, both of which can be linked to human activities.

Sea level

As the sea ice floats in the sea, the sea surface level will not be affected appreciably if the sea ice melts. The current rise in sea level (approximately three millimetres per year) is primarily due to the warming of the seas and oceans; warm water takes up more volume than cold water. A small proportion is due to the melting of inland ice, primarily mountain glaciers right around the globe, for example in the Alps, the Andes and the Himalayas. Some melting of the Greenland ice has been observed over the past five to ten years, but it is not certain whether the Antarctic's large inland ice mass is growing or melting.

Continued warming over the next hundred years will produce a continued rise in sea level. According to the summary presented in the 2007 IPCC report, global sea level could rise by around half a metre by 2100. Subsequent research has shown that the sea level may rise by more than this, perhaps by as much as a metre. Calculations regarding the melting of ice are very uncertain, however. This is particularly true of the contributions from the Greenland ice and Antarctica. This is due to our incomplete knowledge about the dynamics of glaciers. Both the Greenland and the Antarctic ice include large glacial areas that could melt more quickly than has previously been calculated. Continued research and improved observation data from satellites will hopefully lead to more accurate calculations of future glacial melting.

Sea currents

The Gulf Stream transports warm ocean water from the Caribbean, along the east coast of North America, and on towards the North Atlantic and the Arctic. In the Norwegian Sea, the cooled, salty water from the Gulf Stream sinks before returning southwards as a bottom current. This cooling means that heat from the Gulf Stream helps to warm up the North Atlantic, producing a temperature climate in Western Europe and the Nordic Region that is warmer than corresponding regions at the same latitude, such as Alaska and eastern Siberia.

Calculations show that a continued melting of the Greenland ice sheet and increased runoff from Russian and Canadian rivers that flow into the Arctic Basin could result in a weakening of the Gulf Stream. This is because the melting and the runoff will result in an increased amount of fresh water in the Norwegian Sea and the Arctic, which will prevent the Gulf Stream's water from sinking. The Gulf Stream would then be forced to turn further to the south, weakening the transfer of heat to the North Atlantic region. The net effect in Western Europe and the Nordic region would still be warming, but over Iceland and southern parts of Greenland in particular, the weakening of the Gulf Stream might lead to only a small temperature increase or no increase at all. As yet, no clear weakening of the Gulf Stream has been observed, and there are no clear signs of an increase in the influx of fresh water in the North Atlantic.

Permafrost

In line with increased warming in the Arctic, there is an increased risk of melting of the permafrost areas in northern Canada and Siberia. Large amounts of carbon are stored in the permafrost. Melting could result in this carbon being released into the atmosphere in the form of methane gas or carbon dioxide. We don't know what volumes this might entail, but there is a risk of the released greenhouse gases reinforcing global warming.

Precipitation and the spread of deserts

Increased global average temperatures result in an increase in the amount of water vapour in the atmosphere. As a result, it could rain more over those areas where we currently have precipitation. One example of this is the increased risk of torrential rain in parts of North America and Europe. At the same time, areas that currently do not have much precipitation will become even drier. This could be particularly evident in the Mediterranean region. Climate projections show that the Sahara Desert could spread to the east; areas that are currently semi-arid could become dry deserts in the future. At the same time, it might rain more in regions that are currently on the outer edge of tropical rainforest areas, which could actually result in some dry areas becoming fertile.

We are not yet witnessing any clear signs of the spread of deserts that can be attributed directly to global warming, although the parts of the world that have plenty of precipitation have become slightly wetter over the past fifty years, while precipitation has decreased in areas that currently do not receive as much precipitation.

Extreme weather

The number of powerful tropical cyclones over the Atlantic and the Caribbean has increased over the past 30–35 years. This is probably linked to the increasing sea surface temperatures in these areas. If global warming continues, we can expect to see an increased number of powerful tropical storms, although there are no indications that the total number of tropical cyclones will increase.

Extreme storms at Swedish latitudes could become either more common or less common. Different climate projections point in different directions, and it is not possible to identify a clear, uniform trend. Neither is it possible to discern a clear trend from weather observations of storms. Hurricane Gudrun in 2005 was one of a series of powerful storms to have affected Scandinavia in modern times. There are no indications that storms of this kind have become more common during the 20th century.

Sudden changes – tipping points

The risk of abrupt events in the climate system increases in the event of a continued warming. An example of such an abrupt event could be the melting of large ice masses from glacial areas in Greenland and the Antarctic. Another example is a sudden cessation of the Gulf Stream. Neither of these phenomena has occurred over the past 50 years, and can therefore not be related directly to global warming. This does not mean that they could not happen in the future, however, although it is not possible at the moment to say how great this risk is.

During the summer of 2007, dramatic melting of the sea ice cover in the Arctic was witnessed. In the middle of September 2007, the ice cover had decreased markedly compared to the same time the year before. It is true that there is a clear declining trend as regards the sea ice cover in the Arctic, but the change from 2006 to 2007 was far beyond what might be expected solely as a result of this declining trend. In September 2008, too, there was a clear reduction in the sea ice cover, which was also greater than anticipated. A reduction in sea ice during the summer results in increased absorption of solar heat in the sea, and hence reinforces the warming trend. It is speculated that the reduction in sea ice in the Arctic is an example of an unforeseen, abrupt event that is reinforced through a positive feedback. It remains to be seen whether this reduction in ice will persist in future years. If this is the case, it may be the first example we have seen of an abrupt event that is related to global warming.

Erland Källén, Stockholm University

Recommended reading

- Markku Rummukainen and Erland Källén, 2009. *New Climate Science 2006–2009*. Commission on Sustainable Development, Swedish Government Offices (www.regeringen.se/sb/d/11736/a/127388).

Measurements and models – tools for the climate researcher

Measurements and modelling are important research methods for a climate scientist. Which is best when it comes to finding out something about the climate in future? Both are useful when we study the climate, but both also have limitations, writes Markku Rummukainen. Measurements support modelling – and vice versa, so the tools are best used in concert. However, measurements cannot reveal the future to us. With models we can make projections and scenarios for the future – although not perfect ones.

Markku Rummukainen, the Swedish Meteorological and Hydrological Institute (SMHI).

Measurements and modelling are two of the most important tools for scientific climate and climate change research. Both have both potential and limitations, but they also complement each other. Measurements provide us with important glimpses of how the climate system works. Using climate models we can better understand the measurements and also conduct experiments regarding the climate system that do not fit in a laboratory.

Measurement data with a certain level of uncertainty

Climate measurements are carried out for the atmosphere, the oceans, the sea ice, glaciers, ice sheets and snow, as well as the biosphere. They are performed on site, such as at measurement stations, buoys, from aircraft and vessels, and remotely using weather radars and satellites. Some individual measurement series go back hundreds of years, but most of the measurements are from the past 150 years, thanks to modern measuring instruments and established long-term measurement networks.

Measurements are a natural building block for climate science. However, not everything can be measured. In addition, measurements can seldom be used straight off. They must first be analysed. Measurements are always associated with some uncertainty due to the properties of the measuring instruments, how the measurement in question is carried out, when and where the measurement is made. The precision and the representative of the data need to be characterised. Particularly complicated analysis is required for advanced remote analysis data gathered by satellite and radar.

It is not possible to measure everything, everywhere and all the time. An example of this is the global average temperature. It is not measured as such, but is analysed from measurements performed at a large number of locations around the world. However, these locations are not distributed evenly. For example, the measurement points are particularly sparse in the polar regions and the Sahara. This entails certain uncertainty in the results that must be taken into account when putting the collected data together.

It is not easy to build comprehensive insights into the climate's characteristics and behaviour by measured data alone. This is true not only for the future, but also for the past. Still, even though we cannot directly measure things that have already happened, there are methods to measure what the climate was like even in the distant past. Nature has some climate archives of its own, such as ice cores and tree rings. These have grown over time, affected by climate variability and natural climate change. In the ice cores, for example, it is possible to find encapsulated air bubbles that can be analysed, allowing us to determine previous atmospheric concentrations of carbon dioxide and methane. Studies of different isotopes of oxygen and hydrogen tell us about past temperatures. The appearance of tree rings is in turn affected by temperature and precipitation when the trees were growing. The results that emerge are known as proxy data, as they do not relate to the climate itself, but to climate-related properties that can be interpreted back to climate data. Whereas ice cores have preserved climate information from periods far in the past, up to several hundreds of thousands of years, tree rings provide information covering much shorter periods.

The future climate cannot be measured by thermometers or other instruments. Climate models give us an opportunity to make calculations and study scenarios about how things may become.

Climate models are not perfect

A climate model is a synthetic climate system expressed in mathematical terms in the form of a computer program. The model describes properties and fundamental physics relating to e.g. the atmosphere, the Earth's surface, the oceans and the sea ice (see figure on page 77). The most advanced climate models that exist today are three-dimensional general circulation models based on our physical understanding of energy, mass and momentum (mass times velocity). All of these are conserved within closed systems. When it comes to the climate, incoming energy in the form of solar radiation is added, and outgoing energy in the form of thermal radiation is allowed to escape from the Earth, as occurs in the real system.

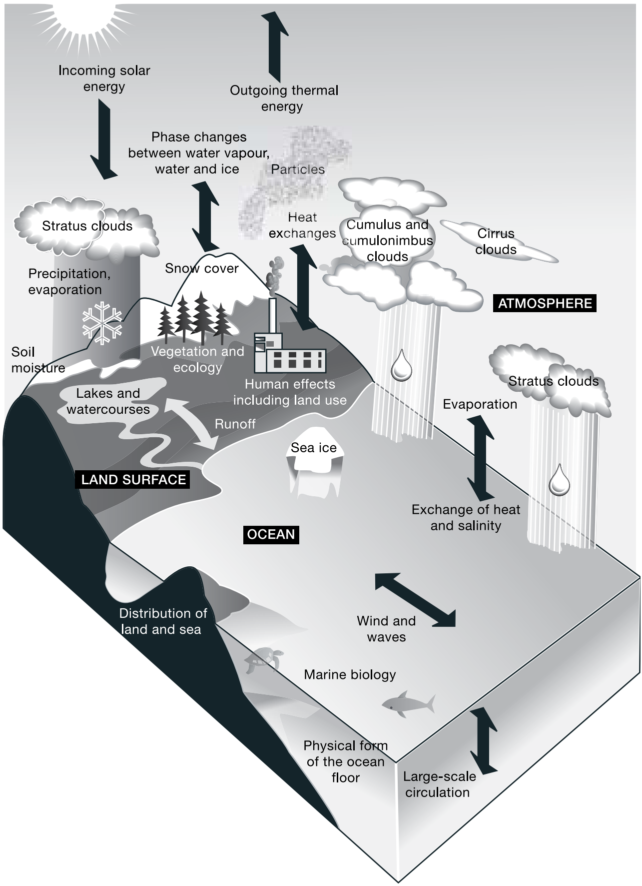
Water in its various phases (snow and ice, liquid, vapour) and the salinity of the sea are also fundamental in the climate system. It is perhaps easier to comprehend the point of this recalling that thermal energy becomes used or released in the conversion between water vapour, liquid water and snow/ice. Salinity variations in turn have an impact on the water density, thereby creating contrasts that drive motion, i.e. ocean currents.

The climate system is extremely complex and it cannot be represented in all its detail, even in the best and most advanced models. Bearing this in mind, climate models are not and cannot be perfect. To the extent measurements have been taken, it is important to make comparisons with the model simulations to evaluate and assess the climate models' capabilities and shortcomings.

A schematic diagram of the climate system. In a climate model, circulation in the atmosphere and sea are simulated with many other processes, such as the formation of clouds and precipitation as well as flows of energy both between and within the ocean and the atmosphere, the formation and melting of ice, etc. The atmosphere, the ocean and the land are modelled in a three-dimensional grid, where values are calculated for temperature, wind, humidity and a wealth of other climate variables. Simulation of the time evolution of these makes up a climate model experiment. Adding assumptions regarding external factors, such as variable solar radiation or changing atmospheric levels of greenhouse gases, both natural and anthropogenic climate changes can be studied. Drawn from Karl and Trenberth, Science 302; 5651, 2003.

Aiming for higher resolution, but also larger systems

Climate is continuous in time and space. For example, the temperature varies on a sliding scale from one time to another or between two places. In climate models, however, the climate system has to be divided into a number of points in order to perform the calculations. In global climate models, the distance between such points can be 100–300 kilometres, while distances of 10–50 kilometres are nowadays achieved in regional climate models. The progression of time is also divided for calculations into a succession of short time steps, ranging from around half an hour up to perhaps an hour in length. These time steps are arranged one after another until a specific period has been simulated. In order to calculate for the climate is this way, numerical methods are required.



Which processes can be calculated explicitly and which have to be parameterised to some extent depends on the resolution of the model. Examples of the latter include convection, small-scale movements such as turbulent mixing in the atmosphere and the sea, the land's heterogeneous structure and aspects of cloud microphysics (how water vapour is converted to and from small droplets, which in turn develop into clouds and eventually into precipitation). Processes such as friction and the absorption of radiation by atmospheric gases in turn involve molecules that naturally cannot be modelled individually. In this context, "parameterisation" relates to process descriptions. These are created with an understanding of the underlying physics and are themselves a kind of model.

In addition to the basic equations, numerical technology and process descriptions, a specification of land and sea distribution as well as their main forms and properties is required. The impact of the Earth's rotation on atmospheric and ocean circulation is also built into the equations. Solar insolation and the composition of the atmosphere, as well as any other impact that is to be included, must also be described. A model can never by complete or perfect. It could also be the case that some fundamental element is absent in all models. For example, up until the beginning of the 1990s, climate models did not give consideration to atmospheric particles. These have some effect on the radiation balance and on the formation of clouds. These effects are now incorporated into many climate models, although there is still considerable uncertainty. One reason for this is that there are only a limited number of measurements of particle quantities and the detailed properties of particles.

Climate models have been used since the 1960s. Discussions are now focusing on increasingly detailed climate models, with sights in the longer term set on a scale of 1–10 kilometres, even in global calculations. At the same time, models are being developed more and more towards Earth System Models. In addition to the atmosphere, land surfaces and the sea, these would incorporate interactive vegetation, atmospheric chemistry, the carbon cycle and possibly the sea's bio-geochemistry. In some research, also including the modelling of society's processes (population, economy, etc.) is starting to be considered. This could result in better and more refined studies of feedbacks and uncertainties. It could also lead to surprises in our understanding. Being able to study new interactions could lead to unexpected effects and new insights.

Are some data better than others?

One might imagine that measurements are worth more than data from models. Occasionally one might also get this feeling from talking to scientists who inveterately conduct research into climate processes by means of measurements and process studies. I have met colleagues who more or less “sniff” at models. This is perhaps caused by the idea that whereas measurements deal with the real climate systems, modelling is about simulation, i.e. calculations of a virtual world. Indeed, even though measurements have their limitations, they are still the closest we can come to reality. In this sense, simulations are just the next best thing. In the same way, I have colleagues who firmly believe in models and do not work with measurements.

In my opinion, co-operation is required, as climate modelling and measurements complement each other. Both result in data about temperature, precipitation, winds, salinity in the sea, soil moisture, snow cover, and so on. Measurements give us information about what is going on, and climate models about where we might be headed. Climate modelling helps us to understand measurements, and measurement to evaluate and improve models. If we cannot model the data that we measure, we probably do not have a true understanding of the climate to which these observations relate.

What will happen in the future?

What should we do in climate research with what cannot be measured, including the future? Should we use climate models? My answer is "Yes, although using common sense". Today's climate models have demonstrated value, and their results stand up well compared to various measurements. Even though climate models are not perfect, they are very useful. Climate modelling is akin to working in a laboratory, as if we were surrounded by test tubes and measuring instruments.

Both measurements and modelling are irreplaceable in climate research, whether we are assessing the climate in the past, the present-day climate or what the climate of the future might be like. In recent years, research supported by climate measurements and research using climate modelling have increasingly joined forces. This is a good development with the promise of better and better knowledge.

Markku Rummukainen is a climate expert at SMHI, Associate Professor of Meteorology at the University of Helsinki, and Adjunct Professor specialising in climate modelling at Lund University. He led the Sweclim programme 2000–2003, was the head of the Rossby Centre climate modelling unit at SMHI 2002–2007 *and now heads the Mistra Swedish research programme on Climate, Impacts and Adaptation. He also carries out research in the Formas-funded project "Models, media and climate change in the Arctic". Markku has participated in the IPCC's latest two scientific assessments published in 2001 and 2007, as well as in the scientific council for climate issues commissioned by the Swedish Government.*

Why should we believe in climate models?

Building a climate model entails balancing many different factors – as if on a knife-edge – some that we know well and others where knowledge is incomplete. Clouds are one Achilles heel, and aerosol particles another. There are also probably things that we don't yet know that we don't know. Still, the models provide a good description of the observed climate system. However, we must never forget that a model is only a model, and not the reality. There is always a risk that we may get the right answer for the wrong reason, writes Michael Tjernström.

Michael Tjernström, Department of Meteorology, Stockholm University.

The issue of man's impact on the climate has become one of the most important environmental issues of our time, particularly since the UN's climate panel, the IPCC, published its most recent report in 2007. This issue has been extremely topical in Sweden since the turn of the century, although the research has been very active for several decades. In recent years, the issue has attracted the interest of the general public, and as a result has also been brought to the fore by politicians and other decision-makers.

From a scientific perspective, the climate issue is atypical within the natural sciences as it cannot be studied through controlled experiments. It is not possible to turn the clock back and test how an alternative climate would have appeared, i.e. a climate without human emissions of greenhouse gases. We only have the world in which we live. This becomes even more problematic if we want to understand how the climate may develop in the future if we assume that societal development will proceed in a particular way – or vice versa if we want to know how we must change society in order to keep the impact on the climate within reasonable limits – and indeed to determine what those limits are.

This is where climate models come in. Using climate models, we are able, together with observations, to attempt an understanding of how the climate system works. If we make a realistic assumption about the future development of greenhouse gas emissions, we can also make projections about the development of the climate in the future. We can also study possible effects of emissions reductions, and provide scientifically based advice to aid political negotiations. The development of today's realistic, coupled global climate models is one of the real breakthroughs of climate research. However, this success also comes at a price, namely that of answering in a credible manner why we should believe in these models, and how well they actually describe the real climate system.

A climate model is not the actual system

In practice, a climate model is a very complicated computer program, a mathematical-numerical synthetic model of the climate system that is sufficiently similar to the real system that it can be used to understand the climate system, to make predictions about the future climate and to assist in the evaluation of various measures.

Taking decisions about the future on the basis of models is nothing remarkable in itself. We take large and small decisions based on various models just about every day. Sometimes these are conceptual – mental models about how various things are related – and sometimes they are more formal, such as mathematical models. Nevertheless, we must always bear in mind that a model – however advanced it might be – is still just a model and not the actual system. Models always have inherent deficiencies and there is always the potential for surprises, for example due to processes that we do not yet properly understand. A climate model is therefore never finished – it must be constantly developed.

Chaos in the climate system

Why then is it so difficult unequivocally to answer the question about the development of the climate – and about the quality of the climate models? One of the most important reasons is the climate system's inherent chaos or, to use another term, its non-linearity. When scientists refer to chaos in this context, we do not mean a random system that is impossible to understand. Instead we mean a system consisting of various processes, each of which can be described and understood in isolation, but where all are dependent on each other in such a way that when they are linked together, they produce a system where one small change in one part of the system can generate an unexpectedly large and apparently random change in another part – or in the entire system.

Let us take another, more down-to-earth example. Imagine you are standing on a bridge over a river that has a series of falls downstream from the bridge. You throw floats repeatedly into the water at exactly the same place, and then check where they end up below the falls and how long their journey took. You will then discover a couple of things. Firstly, if you place two identical floats at the same time at the same place in the river, you will never find them next to each other below the falls. And secondly, no matter how many times you repeat the experiment, floats will never end up in exactly the same place after exactly the same time. This is due to the accumulated effect of all the small differences in the local eddies and whirls that each float experiences uniquely during its journey. These types of variation also exist in the atmosphere; the air behaves like a liquid, even though we cannot see how it moves with the naked eye. This "chaos" is also the reason why the maximum length for a detailed weather forecast is fundamentally restricted, but that is another story entirely.

The things we don't know – and the things we don't know that we don't know

The climate system comprises many different and often complex components that are linked together in just such a chaotic manner. This means that it is not always possible to determine a priori how an individual process influences the climate in the final analysis, even if we understand that process's direct effect. We understand the direct effect of a large number of climate processes, but can often still not determine their significance for the system as a whole, because we can never guess the many different consequential effects or feedbacks. One example of this is the fact that, despite the driving factors for the climate system being strongest in the tropics, the greatest changes take place at high latitudes, especially in the Arctic. The only responsible method of dealing with this is to use a realistic model of the entire climate system. This is possible, at least in theory, although one precondition is that we have to be able to identify, understand and mathematically describe all relevant processes.

And this is where the next problem arises. We understand many processes, such as the direct effect of the greenhouse gases on the Earth's thermal radiation. We understand some other processes reasonably well, but some are so complicated that it is difficult to describe them, such as the effects of cloud. For yet other processes, our knowledge is incomplete and the description deficient. Examples of this include the effects of small particles (aerosols) on the climate, or the interaction between the biosphere and the atmosphere. And finally, scientists can never make reservations for "the unknown unknowns" – processes that we don't know that we don't understand, quite simply because we have not discovered them or their significance yet. Bordering this is the much debated possible effect of the solar wind on cosmic radiation, and its possible effect on aerosols and hence on clouds.

Large and small

Another – and partially related – problem is the enormous range of the climate system, over both time and space. In terms of space, our weather systems and the circulation in the oceans are controlled by processes on a global scale, such as the difference in temperature between the equator and the poles. Another example is the long waves in the atmosphere, Rossby waves (named after the Swedish-American scientist Carl-Gustav Rossby), which span both the entire Northern and the entire Southern Hemisphere. Another is global ocean circulation, for example warm water flowing northwards in the Atlantic, sinking to the bottom in the northern North Atlantic, and then flowing back south before eventually rising to the surface again in the Pacific Ocean or the Indian Ocean. Ocean circulation has a timescale of perhaps a thousand years, while circulation in the atmosphere has a considerably shorter timescale, perhaps just a few weeks. The major periods of glaciation – the ice ages – take place over much longer timescales, and are probably primarily driven by small changes in the Earth's orbit around the sun and the angle of the Earth's axis.

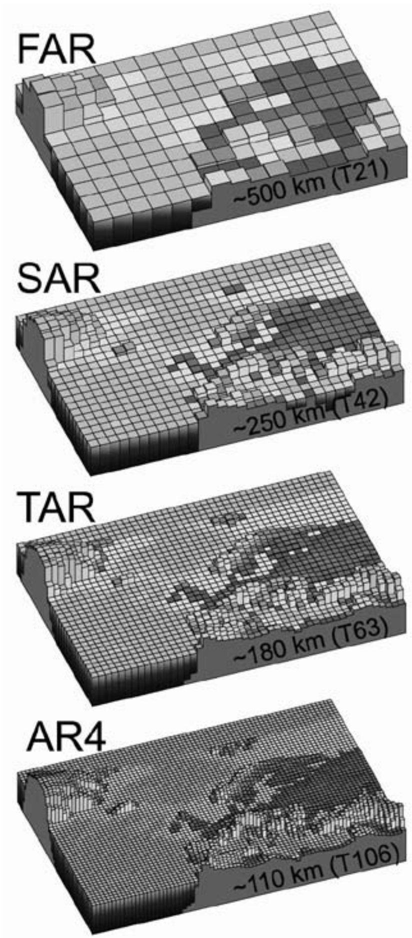
At the other end of the scale we find the very smallest – and fastest – processes, such as the formation of water droplets or ice crystals in clouds, measuring just micrometres. Or the turbulent vortices in the lowest part of the atmosphere that, just like the eddies in the river example above, transport the wind's kinetic energy to the ground where it is dissipated into heat. They also redistribute the energy from the sun's rays and the Earth's thermal radiation between warming and evaporation at the Earth's surface. All of this takes place on scales as small as micrometres and seconds. All of these processes are important for the climate, and none can be neglected.

Deficiencies and weaknesses

One important effect of chaos in a system is that when we formulate the mathematical equations that describe it, they become unsolvable. This does not mean that we cannot calculate the climate, but it does mean that these equations must be replaced with other, approximate equations that are not continuous in time and space. In simple terms, in models the oceans and the atmosphere are built up of a grid of three-dimensional boxes (see figure on page 92). We can then calculate for example how much energy or water flows into and out of each box from the neighbouring boxes, and the net result then affects how the conditions in each box change over time. This is done for each box in space, and is then repeated over and over again in time.

When we are going to simulate a global system, where we have to be able to calculate developments over a prolonged period with limited calculation power, it follows automatically that the size of these boxes – the model resolution – will be limited. This will be a compromise between available computer capacity, the length of the simulation and how quickly we want to access the results. In today's global climate models, the typical size of the smallest processes that can be described directly is around one hundred kilometres. This works reasonably well for describing our most common weather systems, but not for phenomena such as tropical hurricanes. And what happens with all the much smaller processes, such as cloud formation and energy exchange at the Earth's surface?

We try to describe the effects of these small-scale processes statistically rather than describing the



The resolution in the climate models – the size of the calculation boxes – has been developed over time, from the IPCC's first assessment report (FAR 1990) to the most recent (AR4 2007). The second report (SAR) was published in 1996 and the third report (TAR) was published in 2001.

processes themselves in detail. Yet another approximation, in other words. And if the description of an insufficiently understood process affects the model incorrectly, it is all too easy to compensate for the fault "by mistake", by introducing another deficiency in another process – a compensating error – while still being within the bounds of uncertainty in all processes. You can then obtain the correct result, although for the wrong reason.

Quality assurance

The fundamental precondition for credible climate models is that they are based on established physics and chemistry of the system. Climate models are not mystical hocus-pocus, but are founded on established knowledge about processes, based on widely accepted theories and on observations.

So how do we know if models are good or not? There is actually only one way, and that is to evaluate how well they succeed in describing something we already know, such as the climate evolution over the past 150 years, when we have reasonably good measurements of the development of at least some aspects of the climate. And the more observations we generate today, using new, advanced technology, for example with satellites, the more detailed evaluations we can carry out.

Tests using today's modern climate models show that their ability to describe the global temperature trend since the middle of the 19th century is good, assuming we run the models with the best possible estimates of how factors that (we know) affect the climate have varied during this period, such as the sun's variations, greenhouse gases and volcanic eruptions. Such experiments show that the trend in temperatures since around 1960 cannot be explained unless we take man-made changes in greenhouse gases into consideration (cf. figure 2 on page 50). The models also demonstrate a realistic internal variability – the results of the chaos that characterises the climate system.

However, the temperature close to the Earth's surface is a relatively robust climate variable. For other variables, particularly when it comes to cloud and precipitation, the various models differ from each other considerably. The quality of the results for different regions also varies between models. Different models use partially differing assumptions, in particular for the smallest scales, and therefore produce slightly different results, particularly as regards the future. Different climate models have varying degrees of sensitivity, i.e. they react by different amounts of warming to a prescribed change in the concentration of greenhouse gases, even if they produce the same realistic results for the climate from the mid-19th century up until today. For example, it can be shown that there are links between this climate sensitivity in the different models and the way they handle clouds. This entails some uncertainty as to the exact trend in the future – particularly as we don't actually know precisely how large this sensitivity is for the real climate system.

Balancing on a knife edge

In the final analysis, the models are based on accepted knowledge about the climate system, and the only way of improving the models involves increasing our knowledge about this system and its various components. This is the only responsible way of trying to understand the climate and how it will develop in future.

However, building a climate model entails balancing many different factors on a knife-edge – some that we know and understand well and others where the knowledge is incomplete. Despite this, we have to conclude that the models essentially describe the main features of the observed climate very well, even though certain details demonstrate systematic differences between different models. And we must never forget that a model is a model – and in no way reality.

Michael Tjernström is Professor of Meteorology at the Department of Meteorology at Stockholm University, and also works at the Bert Bolin Centre for Climate Research. He conducts research primarily regarding small-scale dynamic processes in the atmosphere, such as turbulence and cloud formation in the atmospheric boundary layer, the lower part of the atmosphere that is directly affected by contact with the Earth's surface. The research is conducted with the aid of both models and field studies into various processes. Over the past decade, the research has primarily focused on processes in the Arctic.

In the light of climate history – researchers should take the initiative in the debate

There are natural variations in the climate, and humans are now in the process of actively influencing the climate system. There is no contradiction in this, and the research community has long since passed this stage of the discussion, writes Per Holmlund. However, there is a great deal that we do not know, and the truths on which we rely occasionally rest on fragile foundations. The scientific community therefore has a responsibility to debate in the media, but to date has opted for a passive approach, answering questions pleasantly but avoiding taking the initiative. This leads to distrust and leaves the field free for climate charlatans.

Per Holmlund, Department of Physical Geography and Quaternary Geology, Stockholm University.

A debate is being conducted about the climate issue in the media that at times is difficult to comprehend. Journalists can challenge us not to believe the climate prophet Al Gore, or even more extreme that we should not even believe in the greenhouse effect. Scientists regularly have to come in to respond to these foolish ideas, but then the discussions die. It is interesting to ask ourselves why this is the case – why don't scientists continue debating with each other in the press?

Since its inception some 20 years ago, the work regarding the IPCC report has been developed to produce an increasingly nuanced and hence complex picture of climate development. At the start, the work focused entirely on climate change being a result of human impact. The climate was assumed to be more or less constant up until the time man came into the picture and disrupted it. This was accepted, despite the fact that there was a wealth of knowledge among climate scientists about how the climate has varied in the past. The situation has improved since then, and the 2007 IPCC report contains a relatively detailed section about natural variations in the climate that have been able to be discerned from ice cores and other paleoclimate archives.

Long-term trend towards a colder climate

Over the past 50 million years, temperature developments have displayed a very marked trend towards a colder climate (figure 1). According to interpretations of sediment cores from seabeds, this cooling has been in the region of 10 degrees Celsius. The sun has not cooled during this period, however. The general interpretation is that the decline in temperature can be explained by a reduced greenhouse effect due to carbon and methane having been bound up

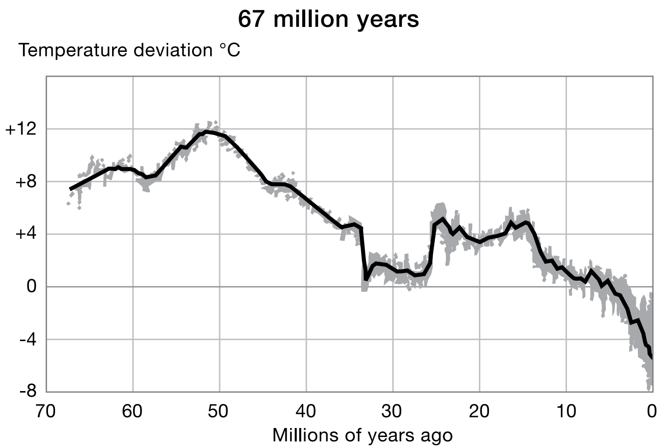


Figure 1. This is how the global temperature has changed over the past 67 million years in relation to the situation today. The temperature scale comprises estimates that are based on oxygen isotope data from the shells of foraminifers in machine drill cores, and are more reliable in the older and warmer period than in the late Ice Age period. The zero level has been set arbitrarily at an assumed current level. (From Zachos et al, Nature 2001)

at the Earth's surface in peat and sediment, and later in permafrost. In addition to a reduced greenhouse effect, tectonic changes primarily in the North Pole region have changed the conditions for heat transfer between low and high latitudes. The distribution of land and sea in this area has changed over time.

Over the past 2.5 million years, there have been very strong fluctuations between ice ages and interglacial periods. During the coldest parts of the ice ages, the temperature in Scandinavia was 15–20 degrees colder than it is today. The ice ages are characterised by cold conditions, but also by very large temperature fluctuations, particularly during the coldest phases. The last ice age (Weichsel) had short warm periods that occurred at one to two thousand year intervals, and slightly longer cold periods at approximately five thousand year intervals (figure 2). These fluctuations were large and proceeded quickly, in some cases moving from an ice age situation to a climate that was ten degrees warmer in the space of one year. When these large, rapid fluctuations occurred in the climate, the Northern Hemisphere looked a little different from today. There were ice sheets in North America, Scandinavia and Siberia, and icebergs and sea ice flowing from the Arctic into the Atlantic weakened the transfer of warm seawater towards northern latitudes. This means that both sea and air currents were different then compared to now.

There were apparently occasional radical changes in the current patterns that gave rise to the major temperature changes.

Little Ice Age ended a hundred years ago

When the last Ice Age ended 10,000 years ago, the climate was warmer than today due to the more powerful solar radiation caused by the Earth's position relative to the sun (figure 3). The ice melted away and the climate stabilised at a high temperature.

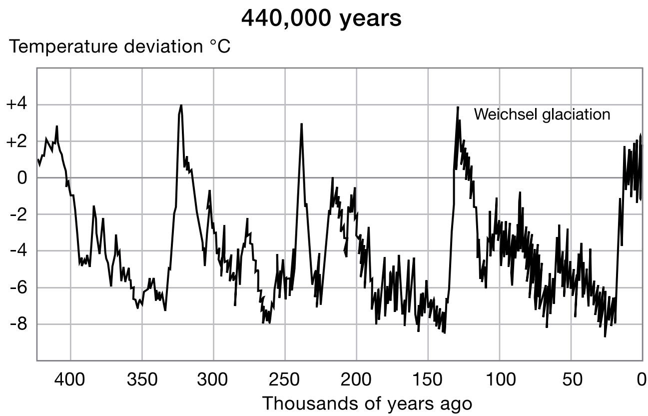


Figure 2. The temperature over the Antarctic over the past 440,000 years, discerned from hydrogen isotopes in drill cores from the Vostok base in East Antarctica. The figure shows the dramatic transitions between ice ages and interglacial periods, as well as the major fluctuations that have occurred within the ice ages. According to data from the Greenland ice sheet, the temperature fluctuations were much greater in the Northern Hemisphere, although the Greenlandic time series only cover one ice age. The time of the most recent ice age, the Weichsel, is indicated in the figure. (From Petit et al, Nature 1999)

It continued to be changeable, although now with smaller variations. The climate has alternated between relatively warm and relatively cold periods, although in recent millennia the long-term trend has been negative in the Northern Hemisphere, i.e. we are moving towards an increasingly cold climate. The most recent really cold period is generally known as the Little Ice Age, and occurred during the 17th, 18th and 19th centuries (figure 4). In the history books we can read about the Swedish army's march across the Great Belt in the winter of 1658, which would

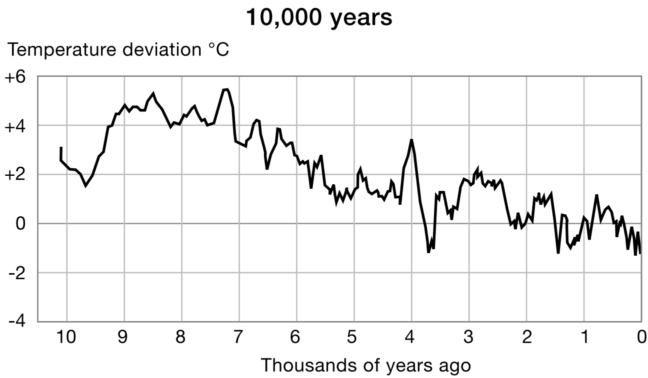


Figure 3. Temperature trend in relation to today's situation in Scandinavia since the end of the Ice Age 10 000 years ago. The temperature graph is weighted, and is based on several different climate proxy data. The graph shows that there was a warm period immediately after the Ice Age, that the trend thereafter has been negative, and that there are relatively large temperature fluctuations within short periods of time. The graph does not include the rise in temperatures witnessed in recent years. (From Bradley et al, PAGES 2002)

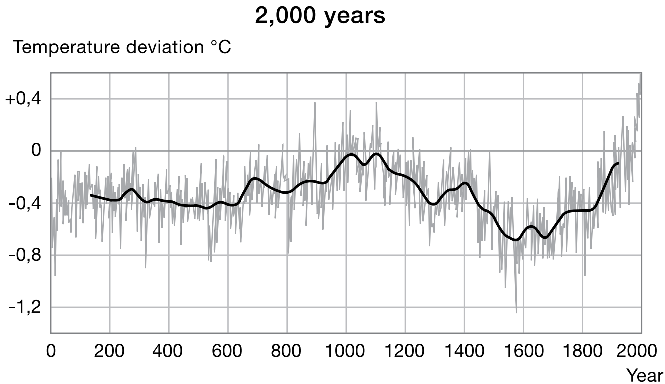


Figure 4. The temperature trend in the Northern Hemisphere over the past two thousand years, based on a number of different temperature proxy series. The graph shows that the climate was warm during the Viking Age and the early Middle Ages, and that we then experienced a cold period, known as the Little Ice Age. The period after 1850 is based on registered measurement values for air temperature and not estimates from proxy data. (From Moberg et al, Nature 2005)

not have been possible during the 20th century and probably not during the middle ages either when the climate was mild. We can also read about the crop failures in the 1860s, and we can monitor when the ice has broken up in the Torne River, which clearly shows that, from the end of the 17th century until a hundred years ago, the springs were much colder than they are today.

The recovery from the Little Ice Age took place in the mid-19th century in Central Europe and at the start of the 20th century in Scandinavia. There are no strong grounds for ascribing this recovery to increasing human activity, as the levels of greenhouse gases were low and the period was followed by a reduction in temperatures. Unfortunately, however, this is often done indirectly by illustrating climate changes in recent times that are probably influenced by man with the way the temperature has risen since the middle of the 19th century.

The hockey stick has come in for criticism

In conjunction with the 2001 IPCC report, a group of researchers led by Michael E. Mann published a summary of the way the temperature in the Northern Hemisphere has changed over the last 1,000 years. This demonstrated a slight cooling up until around 150 years ago, at which point the temperature increased dramatically and almost linearly. This graph is often known as the hockey stick, and was severely criticised right from the time it was published, primarily by geologists. It did not tally with the prevalent perception of what had happened, but at the time of its publication was unfortunately the only available basis for model calculations.

Much more detailed and realistic climate graphs have subsequently been published for this period, but remarkably Mann's hockey stick appears frequently in the most recent IPCC report. One reason for this might be that previous calculations have been carried out using the old graph, and that people want to see how new calculations differ. This is logical and defensible among scientists, but obviously unacceptable for an IPCC report, at least in the section that is targeted at politicians and opinion formers. They have also been criticised for this.

Exaggerated debate according to the geologist

There is an old and well-established difference of opinion between empiricists, who want to test everything against reality, and model-makers who can show off the fact that they have never carried out any field experiments. And as long as this opposition exists, there is an aberration within the debate. Empiricists can look back over millions of years and say that it is normal for the climate to vary by 10 degrees up or down, while on a thousand-year scale it can be seen that there have been dramatic shifts between cold and warm periods. The temperature has now risen over recent decades in a way that is remarkable, although hardly unique. From the perspective of a geologist, for example, the debate surrounding today's climate manifestations is therefore a little exaggerated.

For a theoretically oriented atmospheric physicist, the situation is different. Calculations show unequivocally that an increase in levels of greenhouse gases in the atmosphere is leading to a raised temperature. It is precisely in the most recent decades that the concentrations have reached such levels that we can anticipate a measurable effect. And hey presto, as if to order, the temperature has begun to rise. The statistical link is as clear as a bell, but couldn't this be a natural fluctuation? It is not possible, even for the most hardened theoretician, to say with 100 per cent certainty that what we are witnessing today is caused by human actions.

The IPCC report uses different degrees of the word "likely". When it comes to our current climate, it is established with around 90 per cent certainty that this is affected by human activity. It is not possible to achieve higher levels of certainty, as the models are relatively crude and because there is a natural variation in the climate. If an engineer was to make an assessment that there was a 90 per cent chance that a bridge would collapse within a few decades, it is highly probable that the authorities would implement measures immediately. Nobody would dare to say that, on the other hand, there is a 10 per cent chance of nothing happening!

The debate on whether the recent climate changes have been caused by human activity or not can consequently continue for a long time, as the answer is not known. When the debate is about what the climate will look like in a hundred years, however, the answer is certainly unknown, although according to all calculations, the temperature will be raised as a result of human activity. This is no longer particularly controversial, and hence not that interesting for public debates. The conclusion is that as we are expecting raised temperatures and simultaneously can measure these, it seems irresponsible not to take measures, even though the causal link has not been 100 per cent ascertained.

Glaciers – climate measuring instruments that have to be interpreted correctly

Glaciers are rewarding study objects for climate researchers. The form and size of glaciers are functions of the prevailing climate, and they react very strongly to small variations in the climate and provide unequivocal proof that something has happened. The effects of human impact on the climate are frequently illustrated with the way the glaciers have melted. For Sweden's part, however, the increased melting in recent times only constitutes a small percentage of the change that has been measured over the past century. In order to interpret these excellent climate measuring instruments correctly, it is necessary to conduct long-term series of measurements detailing the development of glaciers, as they often have response times of fifty to a hundred years and, as a consequence, basically never manage to achieve balance with a climate situation.

The fact that the climate has previously varied dramatically, frequently due to natural causes, can hardly be seen as an argument against the belief that humans may be affecting the climate today. Due to variable insolation conditions, we are for example anticipating renewed glaciation within a few tens of thousands of years. It will be colder than it is today, and in around 70,000 years we will experience dramatic glaciation similar to the final stage of the Weichsel ice age. On top of these major variations, there is variability that gives rise to climate fluctuations in the shorter term. Natural variations exist, in other words, and humanity is now also able to affect the climate. There is no contradiction between these assertions, although both factors must be taken into consideration equally in the research. The most recent IPCC report has taken a major step in this direction, and the report has genuinely had a creative effect on the research community.

IPCC on firm scientific ground

Scientists regularly disagree. This has to be the case in order for research to advance. The day we lean back and simply enjoy the conclusions our colleagues arrive at is the day we are finished as scientists. At the same time, however, scientists, even independent ones, are used to studying experiments within given conditions; this is a source of errors, or rather delays in the process. The selection of authors within the IPCC has also sometimes been criticised. This applies in particular to areas such as ice studies and paleoclimatology, which have previously been neglected. However, the effective scientific peer-review system ensures that the conclusions that are reached in end are based on firm scientific grounds.

The disorder in the climate debate in the media is due in part to scientists working with different time perspectives, and in part to scientists not wanting to be associated with fundamentalists who put faith ahead of knowledge. There has been very little objective public debate regarding the IPCC, which is a shame as this would strengthen its position and probably contribute to better research. The IPCC is an ongoing process, however, and I believe that many scientists consider it more important to influence the ongoing work of the IPCC than to debate in the media. From an outside perspective, this can lead to suspicions of cliques or total disorder as regards the state of knowledge.

This is not the situation in my opinion, and it is with great interest that we can now follow the work on the fifth report, which will be published in 2013–2014, and that will hopefully lay an even more stable foundation for climate research than the fourth report. That is a long way away, however, and for democratic reasons in particular, it would be desirable to have a more active debate among scientists in the media.

Per Holmlund is Professor of Glaciology at Stockholm University. He is working on the link between the changing climate and changes in the size of glaciers and ice sheets. The polar regions and the world's mountainous areas are his workplace, and he works both with the longer time perspective and with what is happening to the ice today. He has assisted as a peer-reviewer of the IPCC's 2007 Assessment Report.

The sunspot picture of the sun is outmoded

The Earth's climate is driven by the sun's radiation. However, the sun is not just a white disc 150 million kilometres away, and the number of sunspots does not give a good picture of the sun's activity. Henrik Lundstedt paints a more dynamic portrait of an active corona sun with solar storms and solar winds that affect the climate here on Earth in a number of different ways. As long as IPCC researchers draw their conclusions based on the outdated sunspot image of the sun, they cannot say that they know what impact the sun has on the Earth's climate, he writes.

Henrik Lundstedt, Swedish Institute of Space Physics in Lund.

A solar researcher's contribution to the climate debate is to provide the most recent and the most in-depth picture of how the sun varies, physically and mathematically. In the same way, the other natural science disciplines should contribute with their particular expert knowledge. We can only arrive at a better understanding of the Earth's climate and how it is changing if the various disciplines co-operate. Only then can we also understand the impact of man and of nature on the climate. Let me therefore describe the new picture of the sun and its activity that has emerged in recent years. This picture is in stark contrast to the old-fashioned picture that has generally been used in the climate debate, including by the IPCC. I call the new picture *the corona sun*. I call the old-fashioned picture *the sunspot sun*.

In its fourth assessment report in 2007, the IPCC wrote that changes in the sun's insolation have produced a clear yet very limited warming effect during the period that man's impact on the climate has grown. The IPCC states that anthropogenic greenhouse gases since 1750 have produced a warming effect of around 2.3 watts per square metre of the Earth's surface, while changes in the sun's insolation since 1750 have produced an effect of around 0.12 watts per square metre.

However, the IPCC researchers cannot say that they know how the sun is impacting on our planet if they are using an incorrect picture of the sun.

As a solar researcher with more than thirty years of international experience, I know that we don't yet know how the sun works, but that we will soon be making major breakthroughs. In other words, the IPCC has not described the sun's impact on the climate correctly. The IPCC only calculates the sun's impact in terms of the total radiation, and talks about the maximum and minimum phases of an eleven year sunspot cycle. It mentions a temperature variation of 0.2 degrees on Earth between the highest and lowest radiation levels. This information is based on very awkward compilations of many different sets of data. We solar researchers are now questioning whether we really understand the variation in the sunspot cycle.

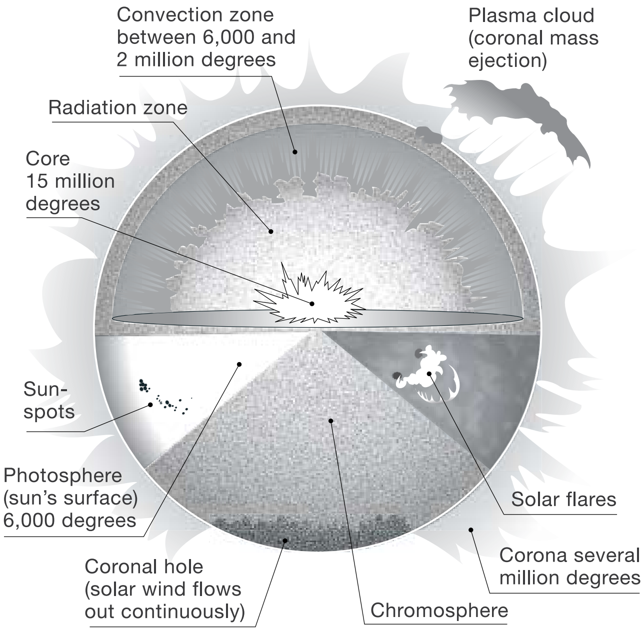
The sun – an ionised ball of gas

The sun is an ionised ball of gas right the way through (a plasma ball). Its internal temperature reaches a massive 15 million degrees (see figure on page 115). This energy is created through fusion, when hydrogen nuclei merge to form helium. The energy is initially transferred through radiation, up to approximately seven-tenths of the sun's radius. It then becomes more efficient to transfer the energy through convection. The temperature has now fallen to 2 million degrees, and we believe that the sun's magnetic field is formed and the sun's global dynamo acts in the boundary layer between the radiation and the convection zones.

When we come to the photosphere or the surface of the sun that we can see with the naked eye, the temperature has fallen to around 6,000 degrees. It is from the photosphere that visible sunlight comes. After the temperature has fallen to a minimum of around 4,300 degrees, it begins to rise in the chromosphere, before reaching several million degrees in the corona. It is in the corona that solar storms such as colossal plasma clouds are ejected (coronal mass ejections), intense solar flares occur and a continuous solar wind flows out from coronal holes. Because of the corona's high temperature and low density, the sun gravity is unable to hold onto the corona. It expands and we experience a solar wind. As the solar wind is a plasma, it also draws with it the sun's magnetic field. The Earth and all the other planets are within the sun's outermost expanding atmosphere and are subjected to intense radiation in conjunction with solar eruptions, energy-rich protons in conjunction with coronal mass ejections and a fast solar wind in conjunction with coronal holes.

The sunspot sun – an old story

In the old-fashioned picture of the sun, the sunspot picture, the sun's activity and its potential to impact on the climate are described on the basis of the number of sunspots, and the sun is viewed as a *white solar disc located 150 million kilometres from the Earth.*



The temperature of the sun varies dramatically from inside the core, where it is 15 million degrees, out through the zones where it is only a few thousand degrees, before rising once more to several million degrees in the corona furthest out. The sun's gravity is unable to hold onto the corona, which expands and gives rise to a solar wind. The Earth and the other planets are within the sun's outermost expanding atmosphere.

Sunspots have been observed for several thousand years. These are areas on the sun's surface (the photosphere) that are dark due to them being at a lower temperature, which in turn has been caused by strong magnetic fields. In the 17th century, we began observing these with telescopes. Galileo was one of the first to do this in 1609 (hence the International Year of Astronomy 2009). In the middle of the 19th century, Heinrich Schwabe discovered that the number of sunspots varies over approximately an eleven-year cycle. After this, many phenomena have been statistically correlated with the sunspot cycle, including variations in the climate.

Edmund Maunder noted that it was not only the length of the sunspot cycles that varied, but also their strength. During the period 1645–1715, the sun did not appear to have any sunspots. With the use of carbon-14 measurements, Jack Eddy succeeded in deducing sunspot activity 5,000 years in the past. He was then able to demonstrate periods of very low activity (Maunder minimums, such as during the Little Ice Age in the 17th and 18th centuries) and other periods of very high activity (Grand maximums, such as during the Middle Ages and over the past 40 years). These periods of low and high activity have coincided with low and high global temperatures. However, we need a physical and a mathematical explanation.

Detailed studies of sunspots show that they are secondary effects of the solar dynamo. The number of sunspots consequently does not give such a good picture of the sun's cyclical activity. Within an international panel called the Cycle 24 Prediction Panel, we have attempted to predict the next sunspot cycle. It is difficult to do this, and I believe that this is because the number of sunspots is not a good indicator of the sun's activity. During the declining phase of cycle 23, a period of low solar activity, we have also experienced powerful solar storms. It is also very interesting to note that the most powerful solar storm known, in September 1859 (the Carrington Event), occurred during a mediocre sunspot cycle.

The corona sun makes society vulnerable

The sunspot picture provides a static image of the sun. Space observations of the sun's corona, on the other hand, give a picture of constant activity. We see that the entire solar corona is connected by magnetic fields, and that energy is being released all the time. An entirely new picture of the sun (the corona sun) has started to emerge, also largely due to the need for forecasts of solar storms and their impact on the Earth's technical systems. In the corona sun picture, the sun's activity is described on *the basis of solar phenomena in the corona (coronal mass ejections, solar flares and solar winds from coronal holes)*, and the Earth is located within the sun's outermost atmospheric corona.

With society's ever greater dependence on high technology and large networks of electrical and gas lines, our eyes have been opened to society's vulnerability in relation to solar storms. Major international research programmes have been initiated. In 1996, the International Space Environment Service (ISES) was established. It is very interesting to note that ISES and the World Meteorological Organization (WMO) have been in contact regarding discussions and future collaboration.

There are now twelve Regional Warning Centres around the world. These RWCs provide information about the sun's weather, the weather in space, as well as forecasts. If there are powerful flares on the sun, we do not fly over the poles as communications between the pilot and ground stations are interrupted. Electric power companies alter their energy distribution in the event of powerful solar and geomagnetic storms in order to avoid power failures. Satellite launches are delayed. The solar weather and the weather in space are now very tangible and real. We have realised that we need to learn to live with the sun. Thanks to warnings and forecasts, catastrophes can be avoided.

The sun's impact on weather systems and climate

The sun's total radiation from the solar surface drives the climate on Earth. Without the sun, there would not be any winds or sea currents at all. The total solar radiation that reaches the Earth's atmosphere is just over 340 watts per square metre. This must be compared with the 0.12 watts per square metre that the IPCC considers that changes in the sun's insolation since 1750 have contributed to the Earth's warming, and the 2.3 watts per square metre that the IPCC considers are being contributed by the additional greenhouse gases since the industrial revolution. The question is how these low values can be estimated with any degree of certainty.

It is interesting in this context to look at how temperature conditions on Earth co-vary with the sun's activity, as well as weather system factors that are related to the sun. In order to understand the sun's changing impact from both a physics and a mathematical perspective, and not only describe it, we are attempting to ascertain the direct impact of solar phenomena. The sun can affect weather systems on Earth both directly and indirectly. High-speed coronal mass ejections produce energy-rich protons that have an impact on the atmosphere's nitrogen oxides and hence on the ozone level in the stratosphere. Solar flares produce powerful UV, extreme UV-(EUV) and X-ray radiation that directly affects the stratosphere. Both coronal mass ejections and the solar wind impact directly on the Earth's magnetosphere and ionosphere by means of the plasma and the magnetic field.

At the start of the 1980s, I demonstrated how fast solar winds can impact on storm activity on Earth via the atmospheric electric field between the Earth's surface and the ionosphere. Another indicator of storm activity is the North Atlantic Oscillation (NAO), which describes a pressure pattern that determines the number of storms as well as the direction of winds and storms moving in over Europe from the Atlantic. An NAO index is calculated from the difference in atmospheric pressure at sea level on Iceland and in the Azores. There is a low pressure centre over Iceland and a high pressure centre over the Azores. In winters when there is a large difference in atmospheric pressure, there are more, stronger winter storms moving on a more northerly trajectory across the Atlantic. This causes the winter in Europe to be warm and wet. In winters when the difference is smaller, we experience cold, dry winters.

As has previously been mentioned, there was a very low level of solar activity during the Maunder Minimum, part of the Little Ice Age. We ought consequently to have had low UV radiation during the Maunder

Minimum. Drew Shindell at NASA has been able to demonstrate that this low UV radiation affected the ozone level, which in turn resulted in a low NAO index and hence lower temperatures in Northern Europe. Shindell's climate models have shown that the winter temperature in Northern Europe fell by 1.5 degrees during the Maunder Minimum, and globally by approximately 0.4 degrees. During the Grand Maximum (1100–1250) there were powerful solar storms and coronal mass ejections.

At the Swedish Institute of Space Physics in Lund, we have also been able to demonstrate that the solar plasma – the solar wind – can also affect atmospheric conditions and the NAO. We have been able to show a strong link between the solar wind's electric field and the NAO. This relationship is strongest during the winter months and after a delay of one month. This delay could be explained by the fact that dramatic variations in the stratospheric circulation can be transmitted down through the troposphere, and that this process takes between 15 and 50 days, which has been observed by a couple of scientists. After being extremely positive for the most part since 1970, the NAO has now decreased again.

It is also interesting to note that the high global temperature in 1998 and the low temperature in 2008 are associated with the El Niño and La Niña sea currents. It is also expected that the change in the Northern Pacific Current in 2008 (the Pacific Decadal Oscillation, PDO) will result in cooler conditions. The El Niño/La Niña phases last for 1–2 years. The PDO phases, on the other hand, last for 20–30 years. The German climate researcher Noel Keelyside therefore predicts that the 0.3 degree global temperature increase that the IPCC has predicted for the next decade will not occur.

Impact via cosmic radiation

In addition to the sun's direct and indirect effects on the Earth's climate mentioned above, there may also be an indirect solar impact via the influx of cosmic radiation. In other words, the more active the sun is, the less cosmic radiation (energy-rich particles) reaches the Earth. The Danish researcher Henrik Svensmark has shown that the variation in cosmic radiation can have an impact on climate through changes in the Earth's cloud coverage. The more cosmic radiation and hence the more particles there are, the more cloud condensation nuclei there are for cloud formation. The results have been widely debated. We do not know enough about cloud formation and the change in the distribution of clouds, but this could be extremely significant for climate change.

In periods of high solar activity, the cosmic radiation is consequently prevented from penetrating the atmosphere. Svensmark and his group believe that this in turn leads to reduced cloud formation at lower altitudes, and hence higher temperatures. In periods of low solar activity, the reverse is true: more cosmic radiation, more low cloud and hence lower temperatures. The Norwegian climate scientist Rasmus Benestad also feels that it is not impossible that the sun might impact on the North Atlantic Oscillation via clouds.

End of Grand Maximum

Solar coronal activity has been very high since the start of the 1970s. However, it began to decline in the mid-1990s. The Ulysses space probe has observed a 20 per cent reduction in solar wind pressure since the middle of the 1990s. UV radiation has fallen by 6 per cent since 1996, and the solar corona's magnetic field has decreased by more than 30 per cent. The modern Grand Maximum consequently appears to have come to an end, and the sun's influence in general is set to decrease. However, we may still experience individual, powerful solar flares, perhaps even super solar storms such as during the Carrington Event.

The Solar Dynamics Observatory (SDO) space probe is being launched at the beginning of 2010. Using this, we will be able for the first time to observe the entire sun at all times. Solar researchers will consequently soon be able to observe the new corona sun continuously. This will be necessary in order for us genuinely to be able to start understanding the sun's impact on the Earth's climate, for instance. The link between sun and climate is a fantastic scientific challenge!

Henrik Lundstedt is an Associate Professor at the Swedish Institute of Space Physics in Lund. He is a member of the Solar Dynamics Observatory (SDO) Science Team. He has worked in collaboration with the solar group at Stanford University in California for many years, and has led several solar and space weather projects within the European Space Agency (ESA). He participated in the ESA project "Influences of Solar Cycles on Earth's Climate".

Extend the climate measures to soot particles!

Global emissions of particles have a major impact on the climate – both warming black soot particles and cooling white particles. The contribution of the soot particles to warming is equivalent to just over half of human carbon dioxide emissions. Replacing biofuels that are used for cooking in the tropics with another technology could be one of the most effective methods of reducing climatic warming, writes Örjan Gustafsson. Particles must be included in future climate agreements, and developed countries must understand that they will benefit from co-financing measures in developing countries.

Photography: Orasis Foto/Mia Åkermark

Örjan Gustafsson, Department of Applied Environmental Science and the Bert Bolin Centre for Climate Research, Stockholm University.

There are various types of particle in the air, known as aerosols, that can have either a warming or a cooling effect on the climate, depending on their composition. In simple terms, it can be said that black/dark particles warm up the air and white/light particles cool it down. Research in recent years has shown that black soot particles cause the equivalent of half the global climate warming for which carbon dioxide is responsible. The soot particles therefore constitute a genuine opportunity to limit our impact on the climate. It is not only easier to reduce emissions of soot particles than emissions of carbon dioxide; a reduction would also have a much more rapid impact, as the lifetime of soot particles in the atmosphere is just a couple of weeks, compared to hundreds of years for carbon dioxide.

Small black soot particles are released into the atmosphere from incomplete burning of both fossil fuels (such as vehicular traffic and coal-fired power stations) and biofuels (such as wood and animal dung used as fuel in households), as well as from open fires and fires in the forest and on savannah land, plus the burning of surplus agricultural products and of arable land after harvesting (burn-beating).

There are major variations between different regions of the world when it comes to the volume of soot and the sources from which the emissions arise. Information about emissions sources and the size of emissions is important in order for society to be able to reach effective decisions regarding which measures should be implemented in order to limit emissions. The best global estimates as regards soot emissions indicate that closed combustion processes for fossil fuels and biofuels are responsible for 60 per cent of emissions, while open fires are responsible for the rest. Developing countries in the tropics, principally India and China, are responsible for 75 per cent of global emissions of soot particles, with the burning of biomass/biofuel being the most important source.

To date, the UN's climate panel (the IPCC) and international climate agreements such as the Kyoto Protocol have not given sufficient consideration to the impact of particles on the climate. This may be because soot and other air particles are the climate debate's "Dark Horse". The IPCC highlights particles as one of the main areas of uncertainty in our understanding of the climate, and hence our ability to predict the future climate.

Black and white particles have entirely different effects

There are a number of properties that influence the effect of air particles on the climate. Unlike greenhouse gases such as carbon dioxide, particles remain in the atmosphere for a much shorter time before they are washed out and/or fall to the Earth's surface. This means that the level of air particles can vary greatly between different parts of the globe, and also between different altitudes in the atmosphere.

In addition, different types of particle have different effects. Black particles such as soot are warmed up by the sun's rays, which leads to an increase in air temperature. However, soot particles also act like sunglasses for the Earth, reducing solar insolation to the Earth's surface. The warming effect is greater than the cooling effect. The combined effect means that, after carbon dioxide, emissions of soot particles are responsible for the most important contribution to anthropogenic climate warming.

Other particles are whiter, including those that are formed by sulphur emissions from the burning of lignite in households and power stations, and those released in volcanic eruptions. This results in the sun's rays being reflected back out into space. The white particles therefore result in a cooling of the globe, compared to the situation if they hadn't been released. There is a moral dilemma here, as these particles also contribute to a major health problem. Should their emissions be limited because they affect health, or retained for a period in order to limit the actual increase in temperature?

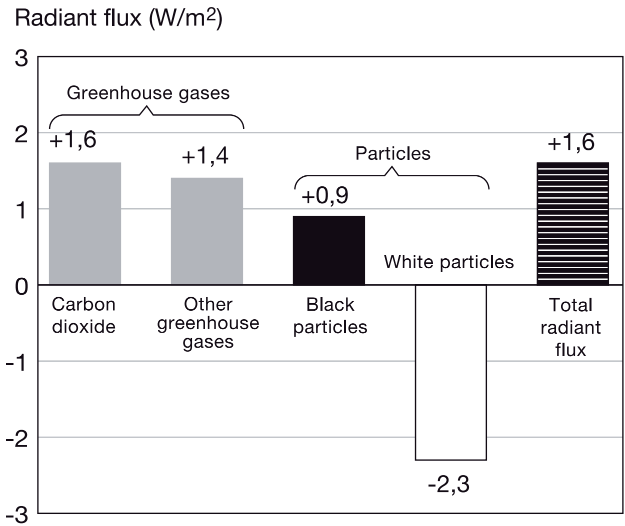
The size of the particles also plays a role, as well as what other types of particle are present in the "particle soup" over certain areas. However, the fact that it is slightly more complicated to understand the effects of the air particles on climate can naturally not be used as an excuse for not paying attention to, and if possible limiting, their negative effects on the climate. We must not leave any stone unturned in our efforts to identify opportunities to limit the risk of the serious consequences that large-scale climate warming would entail.

Radiation effects of particles and greenhouse gases

Soot particles affect the climate in part through different mechanisms than carbon dioxide, but their combined effects can still be compared. Anthropogenic climate warming is reported most frequently as the change that has occurred in the radiant flux (watts per square metre) at the highest levels of the atmosphere since pre-industrial times. A change can consequently either lead to a climate warming effect (positive radiant flux) or a climate cooling effect (negative radiant flux). The radiant flux from anthropogenic carbon dioxide is currently 1.6 watts per square metre (see figure), which corresponds to a potential rise in the average global temperature of approximately 1.4 degrees. Other greenhouse gases combined produce an additional warming effect of 1.4 watts per square metre, producing total warming from greenhouse gases of 3 watts per square metre. If we imagine 60 watt bulbs, this is equivalent to one bulb for every 20 square metres of the Earth's surface. This means that our emissions of greenhouse gases produce the same warming as 25 billion bulbs that are lit day and night.

Soot particles result in a warming of the atmosphere of 2.6 watts per square metre and a cooling (due to the "sunglasses shading effect") radiant flux at the Earth's surface of -1.7 watts per square metre, i.e. combined warming of approximately 0.9 watts per square metre (see figure). The radiant flux of the white air particles has an overall cooling effect in the region of -2.3 watts per square metre. The combined effect of the air particles consequently has a cooling effect, which currently masks around half of the climate warming that we actually "deserve" due to the greenhouse gas emissions that have already occurred. There is currently some uncertainty as to the true extent of this masking effect caused by air particles. The air particles are estimated to mask between a quarter and three-quarters of the warming that greenhouse gases would produce if there were no air particles.

Effects on radiation balance of greenhouse gases and particles



The total warming from carbon dioxide and other greenhouse gases is approximately 3 watts per square metre. Black particles produce warming of 0.9 watts per square metre, while white particles cool by -2.3 watts per square metre. In total, air particles mask around half of the climate warming that we actually "deserve".

Soot particles and brown dust clouds

Anyone who has visited countries such as India and China will have noticed that the air can be filled with a greyish-brown haze. The acrid odour from the tens of millions of open fires that are lit every day is mixed with emissions from traffic and restrict visibility. The potential for sunlight to penetrate the atmosphere's thin layers is restricted in the same way.

Once they are in the air, soot particles mix with other emissions such as sulphates, nitrates, organic material and dust whipped up from the ground, forming brown dust clouds. Various measurement campaigns using both land-based equipment and satellites have demonstrated the global spread of these soot-laden brown dust clouds, although developing countries in the tropics are the worst affected. As it is also in such areas where the sun shines most strongly, the warming effect from soot in the atmosphere is particularly great here. It is estimated that three billion people live under the direct influence of brown dust clouds.

Dark glaciers melt more rapidly

Another worrying effect of the soot particles in the gigantic brown dust clouds over Asia is their contribution to the ongoing melting of many glaciers in the Himalayas. This melting is due to the soot's warming of the air over the region, and probably also to the precipitation of soot onto the glaciers. The soot particles are present from ground level up to an altitude of approximately 4 kilometres. When this soot-warmed parcel of air sweeps in over the Himalayas, it leads to the accelerated melting of snow and ice. "Soot soiling" on the surface of snow and ice also makes that land darker, with the result that its reflecting capacity (albedo) is reduced. As dark surfaces heat up more than light ones, soot in the snow also leads to increased melting.

The Himalayas' glaciers help to even out the water flow in the major rivers, which supply almost 2 billion people with fresh water. If there were significantly fewer and smaller glaciers, there is a risk that the rivers might dry out during the warm, dry pre-monsoon period from April to June, which could have serious consequences for the population in the river valleys. A similar effect on albedo has been reported from the Arctic. When the soot falls onto snow and ice surfaces in the Arctic, this leads to warming and, as a result, melting. More meltwater in the surface water in the Arctic Ocean could also prevent deep water forming in the Arctic, as the surface water would become less salty and have a lower density than the saltier water further down. Deep water formation is an important process for the entire global ocean circulation.

Another serious climate effect of the soot particles is that they are believed to influence the cycle of water. Reduced evaporation from the soot-shaded and hence cooler Indian Ocean will result in reduced monsoon rains in India. In China, a south/north displacement of where it rains is related to the soot-rich dust clouds.

We can buy ourselves time

There is no doubt that soot particles play a major role in anthropogenic climate warming. Soot particles were not included in the 1997 Kyoto Protocol. In future climate agreements, we need to identify new, creative solutions in order also to include these climate-affecting substances that, in comparison with carbon dioxide, are short-lived and not well-mixed in the atmosphere.

These short-lived influences on the climate represent an opportunity for us to “buy time” in order to avoid major climate effects, as a restriction of their emissions would reduce or at least delay climate warming more quickly. Such a climate-motivated reduction in soot particle emissions would bring with it a number of positive bonus effects, including improved air quality and hence a reduction in respiratory and cardiovascular diseases. The World Health Organization (WHO) estimates that more than half a million people die prematurely each year in India alone due to particle emissions that contain soot.

Yardstick for cost-effective emissions limitations

In order to facilitate comparisons between emissions limitations regarding soot particles and greenhouse gases, a global warming potential (GWP) has been estimated for soot particles. The GWP scale is relative, and the climate impact of all other substances is compared with carbon dioxide, whose GWP has been set at 1. A carbon atom in a soot particle is estimated to have a GWP in the region of 2,200 (uncertainty range 700–4,700) over a twenty year period. The uncertainty regarding soot particles' GWP is due to the fact that soot particles affect the climate in more complicated ways than carbon dioxide. The GWP scale itself has been questioned as a common yardstick for both long-lasting and short-lasting factors influencing climate. Nevertheless, with a GWP value for soot particles, it is possible to start evaluating which emissions measures are more effective than emissions limitations for carbon dioxide. One weakness in this method is that it does not include the additional effects that soot particle emissions have, for example on the melting of ice and snow as well as on human health. This (too low) GWP for soot particles is still a starting point for evaluating the cost-effectiveness of various alternative measures.

Small-scale combustion systems are often more polluting, as large systems normally have higher combustion efficiency and flue gas cleaning. It is no longer as cost-effective to tackle coal-fired power stations and car engines in order to achieve a reduction in soot emissions. Emissions calculations show that

Soot-free cooking techniques – financially defensible

More than 3 billion people cook food over open fires made with fuels such as wood, animal dung, coal briquettes and lignite. The combustion efficiency is often low, resulting in high emissions of many substances, including soot particles.

Alternative low-tech solutions are available. Soot emissions can be limited by switching to biogas, closed pellet ovens and solar ovens. There are already examples of successful projects of this type in both India and China. It has been estimated that the cost of measures for this type of cooking (purely with regard to the direct climate effect) over a 20-year perspective is SEK 2–90 (roughly 0.2–9 euro) per tonne of carbon dioxide equivalents for wood fuel and SEK 1–16 for lignite. With prices of emissions credits for carbon dioxide of more than SEK 100 per tonne of carbon dioxide equivalents, countries in Europe, for example, should feel relatively secure that an investment in technology for cleaner cooking fuels in southern and eastern Asia would be financially defensible already based on the direct climate effect. A climate modelling study has shown that if we succeed in switching to soot-free cooking technology in India, this would entail a reduction of more than 60 per cent in the soot particle load over southern Asia.

diesel engines that do not have the latest cleaning technology, wood for heating and cooking, as well as burn-beating in developing countries, can be the most effective sources to rectify in order to reduce the impact on climate from soot emissions. By combining GWP with the costs that would be entailed by limiting soot emissions from various sources (through cleaning technology or by replacing the energy source), it is possible to compare the cost-effectiveness of various alternatives.

International partnership for reduced soot emissions

There are many reasons for restricting soot emissions. The greatest immediate motivation for developing countries is possibly the improvement in public health, while it is in the interests of developed countries to co-finance these measures primarily on the basis of the global climate situation.

Many studies are now showing that:

- soot particles are responsible for climate warming that is equivalent to approximately half the warming caused by man's emissions of carbon dioxide
- the greatest soot emissions come from small-scale burning of biofuels
- in the tropics, limiting soot emissions from household use of biofuels for cooking could be the most effective measure for reducing climate warming.

Even though it would be extremely desirable for soot particles to be included in future international climate agreements, we should simultaneously seek a way, within the international collaboration, to take a broader, overall grip of the many effects that soot particles have on health, climate and development. Such an analysis would probably lead to the conclusion that the soot should be eliminated.

Örjan Gustafsson is a Professor at the Department of Applied Environmental Science and the Bert Bolin Centre for Climate Research, Stockholm University. His research group studies areas such as the links between the climate and the large-scale carbon cycle. At the time of writing, he is running a project within Formas aimed at determining the sources of soot particles in the dust cloud over southern Asia using carbon-14 dating.

Uncritical data mining behind criticism of the IPCC

The climate has varied dramatically in the past, so why should today's situation be unusual? The sun must surely still be more important than man's impact on the climate! These are two of many claims that Eigil Kaas sets about answering. He distinguishes between feedbacks and climate change drivers. The magnitude of past climate variations was largely due to feedbacks. The driving factors such as the strength of the sun and fluctuations in the Earth's orbit around the sun only had modest direct impact. Today's trend of rising temperatures is mainly due to human climate drivers.

Eigil Kaas, Niels Bohr Institute, University of Copenhagen.

Sometimes one gets the impression from the public debate that current and future climate changes are much more uncertain and controversial than is stated by the large majority of climate scientists, for example in the IPCC reports. However, most of the criticism against the IPCC is based on insufficient understanding or an unwillingness to accept the physics of the climate system, or on uncritical use of various data sources. A number of claims have arisen in the debate. There is not room to deal with all of these here, so I have selected some that appear to be quite persistent.

Claim 1. The climate has varied dramatically before. Why should anthropogenic climate change be a problem?

It is absolutely true that the climate has varied dramatically in the past. There have been both much warmer and much colder periods than today, and we largely know why the climate changed. There are only two factors that can contribute to the long-term global average climate, namely the amount of solar radiation that is absorbed by the planet, and changes in the strength of the greenhouse effect.

A number of *natural climate drivers* such as changes in the sun's light intensity and fluctuations in the Earth's orbit around the sun triggered variations in the past. The direct warming or cooling effects of these drivers were relatively small. However, earlier climate changes could still be large as a number of feedback mechanisms were operating. Such feedbacks reinforce the initial disturbances triggered by the driver and lead to further changes, both in the amount of absorbed solar radiation and in the strength of the greenhouse effect.

An example is the ice age fluctuations (ice ages and interglacial periods) that have characterised the Earth's climate over the past one to two million years. Most researchers agree that variations in the Earth's orbit around the sun caused small variations in the amount of absorbed solar radiation, and that these variations were then reinforced greatly by at least four interacting feedbacks: the albedo (reflecting capacity) of ice and snow covered surfaces, water vapour, carbon dioxide (CO_2) and methane (CH_4). Let's say that there was an ice age, and that an increase in the sunlight caused a small, initial warming. This lead to less ice and snow on the Earth's surface, which then became darker. There was then less reflection from the Earth, more solar radiation was absorbed and the Earth became even warmer. When the climate gradually became warmer, the atmosphere could hold more water vapour. This triggered an increased greenhouse effect, as water vapour is the dominant greenhouse gas. In a warmer climate, carbon dioxide was released from the oceans. As a result, there was more carbon dioxide in the atmosphere, and the greenhouse effect then increased further. In the warmer climate, more methane was also released from the land and sea beds, with the consequence that there was more of this powerful greenhouse gas in the atmosphere. The initial small heating was consequently reinforced by these four positive feedbacks, resulting in a much more powerful heating of the planet.

Let's say instead that there was an interglacial period, and that a natural driver affecting the climate acted in the opposite direction so that there was cooling initially. In this situation, the reinforcing feedbacks also acted, although in the other direction, so that less solar radiation was absorbed and the amount of greenhouse gases decreased. In this case, it was instead the initial cooling that was reinforced and became more powerful as a result of the four feedbacks.

Human activity leads to large emissions of carbon dioxide and other gases and particles. These are *anthropogenic drivers affecting climate*. While carbon dioxide acts as an important feedback during ice ages, human emission of this gas is a driver that affects climate, i.e. in this case it is not a feedback. Carbon that has been buried deep under the ground for millions of years is suddenly released into the atmosphere. This leads to changes in the natural carbon cycle, including biological, chemical and physical processes in the atmosphere, in the oceans and on land surfaces. The current increase in human emissions is important as it is comparable in magnitude to the variations in the natural drivers that affected the climate and the associated CO_2 and CH_4 feedbacks over the last few million years.

Claim 2. The temperature controls the carbon dioxide concentration – not vice versa.

Variations in the concentration of carbon dioxide appear to have lagged behind the temperature variations during ice age fluctuations, i.e. the temperature changed first as a result of altered insolation, and the carbon dioxide concentration did not change until perhaps a thousand years later. Climate sceptics therefore claim that the increased carbon dioxide concentration must be a consequence of climate changes, and not a driver that is triggering them. This seems correct when we are talking about ice ages (even though the extent of the lag is fairly uncertain). The problem is that this has been used to argue that man's carbon dioxide emissions are insignificant in relation to climate change today.

The fact that the carbon dioxide graph lagged behind the temperature graph during the final stage of an ice age means that the carbon dioxide was acting as a slow feedback. When more sunlight was absorbed the temperature rose, and the ocean's ability to store carbon dioxide decreased. As a result, the atmospheric carbon dioxide concentration rose, the greenhouse effect increased and the temperature increase was thus reinforced. In the current situation we also have a reinforcing cycle, although this has not been driven by increased insolation but rather by our emissions of carbon dioxide from fossil fuels (figure 1).

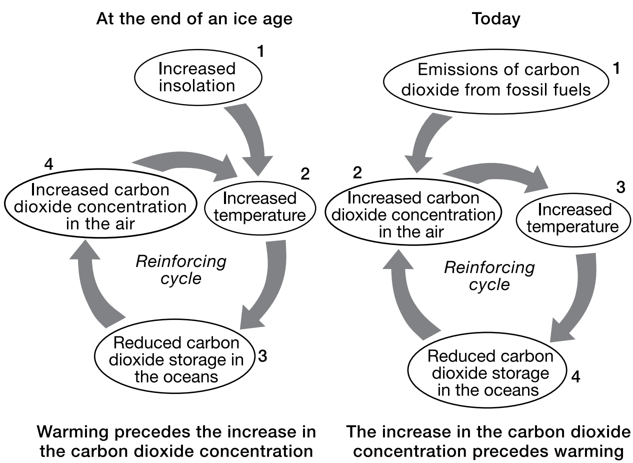


Figure 1. Is the temperature controlled by the carbon dioxide concentration – or vice versa? What was true during ice age fluctuations is not true today. (Source: Swedish Environmental Protection Agency 2007)

Claim 3. Water vapour is more important than carbon dioxide as a greenhouse gas. An increasing amount of vapour could therefore be the main cause of the warming that is taking place.

It is true that water vapour is the most important greenhouse gas. This has been known for decades. However, as has been explained above, water vapour is a feedback and not a driver that is triggering the climate change. According to many climate model calculations, water vapour is the dominant feedback, and hence always an important amplifier of climate change, whatever primary driver is affecting the climate.

Claim 4. The sun's indirect influence via a change in the flux of cosmic rays is much more important than human climate impact.

It has been proposed that climate variations can be explained by varying fluxes of energetic cosmic radiation. The idea is that variations in cosmic radiation lead to variations in the ionisation of the lower troposphere (below 3–5 km), and that this ionisation in turn should stimulate the formation of small particles known as cloud condensation nuclei. Periods dominated by a high flux of cosmic radiation would consequently also be dominated by increased ionisation and hence a greater concentration of cloud condensation nuclei, making clouds at a low altitude whiter and causing them to last longer. This would result in a cooling of the climate, as these white clouds have a high albedo, i.e. they reflect solar radiation effectively.

When cosmic radiation is low, the opposite would apply. Low-level clouds would then be less white and less widespread, with relative warming of the climate as a consequence. The link between cosmic radiation and clouds is often referred to as an indirect influence from the sun, as the flux of cosmic radiation reaching the Earth is altered by the sun's activity. High solar activity implies a high level of protection against cosmic radiation and hence a smaller flux and, according to the theory, less white clouds and subsequent warming. Low solar activity entails the reverse – low protection against cosmic radiation, a larger flux, more white clouds and subsequent cooling.

This is an interesting idea and the mechanism may have been a relevant driver for some past climate variations. It is, however, extremely doubtful whether it has contributed to global warming in the past 30–50 years. The temperature has risen despite the fact that there has not been any general downward trend as regards the cosmic radiation flux. Figure 2 compares the observed global temperature close to the Earth's surface with the cosmic radiation value.

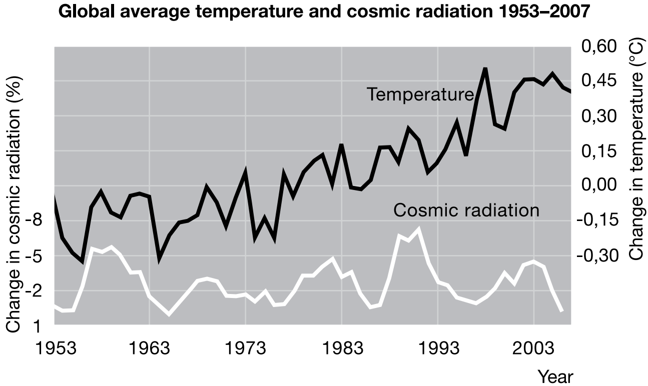


Figure 2. Measured global average temperature (upper graph) and percentage variation in the flux of cosmic radiation (lower graph). Note that the scale for cosmic radiation is reversed. It should therefore correspond to the temperature scale if claim 4 is true. When the cosmic radiation is low (at peaks in the lower curve), there should, according to claim 4, be less white clouds and hence it should be warmer. As can be seen from the figure, this is not the actual situation. (Source: Bo M. Vinther, University of Copenhagen)

There are no signs of a decreasing cosmic radiation trend, whereas there is clearly a rising trend as regards the temperature.

Claim 5. The increase in carbon dioxide since pre-industrial times is not due to human emissions, but can be entirely a consequence of warming.

As has been discussed above, carbon dioxide acted as a slow feedback during ice ages. Even though the mechanisms have not been fully understood yet, it is obvious that this process was related to the interaction between the world's oceans and the atmosphere. Such an interaction is slow, and as a result this feedback may not be noticeable over such a short period as the last 100–150 years of increasing temperature. The interaction with the natural carbon in soils on land is more rapid. Thus, a very small proportion of the observed increase in carbon dioxide could – at least in principle – be ascribed to the rising temperature.

In order to understand most of the increase in carbon dioxide, we have to look at man's emissions and what happens to the released carbon dioxide. The amount of fossil fuel we have used since preindustrial times is fairly well known. There are also less certain estimates of other emissions of carbon dioxide into the atmosphere, including the effects of deforestation and cement production. In terms of pure carbon, man's emissions during the industrial age amount to approximately 500 billion tonnes. If all of this carbon was stored in the atmosphere, the concentration today would be around 500 ppm, as opposed to the actual concentration of around 385 ppm (2008). In other words, there has been a net reduction in the amount of carbon in the atmosphere.

One of the most convincing arguments that fossil fuel combustion causes an increasing concentration of carbon dioxide in the atmosphere can be obtained by measuring the isotopic composition of the carbon. A normal carbon atom (^{12}C) has six protons and six neutrons in the nucleus. The heavier isotopes ^{13}C and ^{14}C have six protons, like normal carbon, but seven and eight neutrons respectively. The natural composition of carbon in fossil fuels and biomass differs from the natural composition in the oceans, such that there is less of the heavy, stable carbon isotope ^{13}C in fossil fuels and biomass than there is in seawater. Isotopic investigations show that the oceans have absorbed approximately a third of the carbon that has been produced by burning. Such investigations also eliminate the possibility that the atmospheric increase in carbon could come from the oceans, as the atmospheric isotopic composition changes towards the composition in fossil fuels, and not towards the composition in natural marine carbon.

The table on next page shows the amount of carbon emissions from cement production and the burning of fossil fuels. These emissions have increased since the 1980s. The table also shows the amount by which the carbon stored in the atmosphere has increased compared to pre-industrial times as a consequence of emissions. The fraction of carbon emissions that is not stored in the atmosphere is (as shown in the table) absorbed both in the oceans and on land. The oceans absorb more carbon than they release, so the net absorption is positive. The net absorption on land is also positive, which means that growth in biomass through increased photosynthesis, primarily at higher latitudes, seems to "overcome" the effect of deforestation mainly taking place in the tropics.

Estimated annual changes compared to before industrialisation. The unit is gigatonnes (billions of tonnes) of carbon per year. Note that the "net absorption on land" includes the combined effect of tropical deforestation and increasing photosynthetic absorption on land primarily at higher latitudes. (Source: IPCC AR4)

	1980s (gigatonnes carbon/year)	**1990s (gigatonnes carbon/year)**	**2000–2005 (gigatonnes carbon/year)**
Emissions from fossil fuels and cement production	5.4±0.3	6.4±0.4	7.2±0.3
Increase in atmospheric concentration	3.3±0.1	3.2±0.1	4.1±0.1
Absorption in the oceans	1.8±0.8	2.2±0.4	2.2±0.5
Net absorption on land	0.3±0.9	1.0±0.6	0.9±0.6

Claim 6. Climate models are only models – why should we trust them?

Climate models are the fundamental scientific tools that are used to assess future climate changes. There will always be certain compromises in such models with regard to how reliably and in how much detail the known physical and biogeochemical processes are incorporated. In order to evaluate how well the models deal with the most fundamental processes, their output data are compared with measured data. Such studies clearly show that climate models are capable of simulating the fundamental processes in a convincing way. This applies for example to the geographic distribution of precipitation, temperature and wind. An even more important conclusion is that comparisons with satellite measurements in particular strongly indicate that the fundamental feedbacks triggered by climate variations over recent decades are also captured by the models. Finally, climate models can replicate the general evolution in global mean temperature (see figure 2 on page 50).

Claim 7. The global temperature has not increased since 1998. However, carbon dioxide has risen during the same period, and therefore it cannot be important.

It is pointless to "blindly" use the observed temperature over a ten-year period to establish whether a particular type of climate driver has been important or not during the period. Several types of natural climate variation occur on decadal time scales. Such variations are related to thermal transports in the oceans, i.e. the redistribution of heat, and the interaction between the atmosphere and the oceans, which can give rise to the temporary storage of heat in the oceans. It is therefore necessary to analyse and eliminate the influence of such processes on the observed temperature trend when we are looking at changes in the climate drivers.

The fact that the increasing temperature trend has been weak since 1998 is due to the temperature in that year being dominated by a strong El Niño event in the Pacific Ocean, with the result that an abnormally large volume of warm water was exposed at the surface over large areas in the Ocean's tropical regions. The years since 1998 have actually been warm compared to the preceding decades, and there is a strong warming trend. El Niño is a typical example of natural climate fluctuations that are not driven directly by anthropogenic circumstances, the impact of the sun or volcanic eruptions. Such natural climate variations can temporarily reinforce or mask an underlying trend. Over the past 5–7 years, there has actually been a weak, cooling, natural climate driver, as the sun is currently close to the minimum phase in its eleven-year cycle.

Claim 8. The observed temperature in the atmosphere is not rising as much as the climate models say.

The observed warming over the past 50 years corresponds quite closely with the warming that is simulated in climate models. This is true not only at the Earth's surface, but also higher up and in various parts of the world. It is occasionally highlighted that, higher up in the middle and upper troposphere (an altitude of 5–10 kilometres), the models simulate a level of warming that is greater than close to the Earth's surface, whereas this does not appear to be the case in observations. This was true until a couple of years ago, when the gap between models and observations began to shrink. Two principal reasons for this were the inclusion of the cooling effect of particles in the models, along with improved analysis of measurement data from weather balloons and satellites.

All types of temperature observation in the troposphere and higher up in the stratosphere suffer from significant homogeneity problems. This means that changes in instruments, the number and type of observations, as well as the observational conditions, can result in artificial changes that arise solely due to the way the observations were conducted. Such problems have been a primary reason for the apparent difference between models and observations.

Ill-informed data mining

The climate-sceptical arguments have been dealt with very thoroughly in international scientific journals over the past 25 years or so. This scientific debate has significantly increased our understanding of the climate system, and almost all scientists now agree that human activities have initiated a rise in global temperatures that will increase in future decades.

The climate sceptics often twist the argument in a way that is completely out of step with fundamental scientific knowledge. This is true for example of the mixing up of climate-influencing factors and feedbacks. Many climate sceptics demonstrate an embarrassing lack of insight into the scientific literature. Or they devote themselves to data mining, i.e. searching uncritically for any observations that support a climate-sceptic argument. As there is an enormous amount of climate data available, they will normally find what they are looking for. However, a more detailed examination often shows that there are mistakes in the data they have found.

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Who can we trust?

Is it true, as is often claimed, that science is united around the theory that global warming is man-made? In order to answer this question, we need to specify what is meant both by the theory in question and by scientific consensus. Olle Häggström examines these notions and comes to the conclusion that science is in agreement that, at present, there are no reasonable grounds to believe that the theory is incorrect.

Olle Häggström, Mathematical Sciences,
Chalmers University of Technology.

Think for yourself! Think critically! For hundreds of years, these slogans by 18th century Enlightenment philosophers have helped people to break free from the dogmatic thought systems of the church and other authorities, and they are still valuable today.

However, living up to the slogans' ideals can today seem like a daunting task. As the mass of knowledge provided by science branches out to become increasingly vast, there are a number of issues that involve advanced and topical research, and that at the same time must be taken into consideration by democratically minded members of society.

We can find obvious examples of these within the climate issue: Should society take steps to reduce greenhouse gas emissions that otherwise risk exacerbating an already accelerating climate change? Or should we rather focus on preparing ourselves for climate changes that will occur, regardless of what we do about greenhouse gas emissions? Or is the entire climate problem exaggerated, and would we therefore be better to ignore it and focus our efforts on other, more acute problems?

These questions affect the future of all of us, and we cannot simply hand them over to a small group of experts to reach decisions on their own. Citizens need to form an opinion. However, in order to make sensible and rational decisions, we need to know a considerable amount within the field of natural sciences. To adopt a stance on whether there is any point in reducing our greenhouse gas emissions in order to slow down global warming, we first and foremost need to have an understanding of whether these emissions influence the climate, and if so how much.

So what attitude should a committed member of society take towards scientific issues of this kind? I will use the climate issue as an example to discuss what might be a reasonable attitude. Much of the current debate surrounding the climate issue has focused on whether there is scientific consensus – agreement – regarding the theory of anthropogenic (man-made) global warming. I will start by discussing the concept of scientific consensus in principle, and only then will I look at whether such consensus can be deemed to exist in the climate field and, if so, what this means.

What does scientific consensus mean?

The core issue is: How should we rationally go about adopting a position on scientific issues when there are conflicting messages regarding what the situation actually is? A typical example is the issue of whether the greenhouse gas emissions that we humans cause (primarily carbon dioxide) in turn cause global warming. We are often told that such a causal link exists, although at times we also come across pronouncements that firmly deny that this is the case. So how should we decide who is right and who is wrong?

An initial approach might be to rely on opinion polls – the simple counting of how many think this and how many think that – and then go with the majority. This strikes me as an extremely unreliable and even objectionable method. People can (and should) certainly vote regarding political values – but about facts? Facts are what they are, regardless of what the majority happen to think about the issue. Hence, if the notion of consensus is to serve as a guide to the truth, it needs to be more refined that simply summarising votes or opinion polls.

In my opinion, it is better not to focus on the majority, but instead on who has the best arguments, in the sense of logically coherent and sensible scientific reasoning that is supported by observations. This is the ideal. Unfortunately, this is generally unachievable in practice, for the simple reason that most of us do not possess the knowledge required in order to determine for ourselves the quality and strength of the scientific arguments. For the vast majority, acquiring this knowledge would require at least a few years of university studies in the subject in question – and often more.

In practice, we have no choice other than to rely on somebody else whom we have reason to believe possesses greater knowledge than we do in the area in question. But who? When given the choice between the prophet, the priest and the scientist, I would recommend the scientist – simply because science has, in recent centuries, convincingly established itself as the best and most accessible route to knowledge about how the world about us works.

Scientific journals as a stamp of quality

In other words, if we do not ourselves have the time, the energy or the ability to examine the scientific arguments in detail – let's trust the scientists! If all scientists in a field give the same answer to the issue in question, then it is clear what stance we should adopt. But what should we do if this is not the case? Should we follow the majority opinion among the scientists? I have already discussed the problem with relying on majorities, and there is an additional problem here regarding how we should define scientists as a group. Should we go by academic qualifications and titles, or should only those who, say, have published in a scientific journal in the area in question during the past five years be counted as scientists? Whatever approach we take to the definition, there is a certain amount of arbitrariness. Even worse, there is always a risk that individual scientists will express opinions based not on scientific considerations, but rather on political or religious convictions, for example.

In my view, the best solution to this problem is to look for the answer not from a particular category of scientists as *individuals*, but instead in the *scientific journal literature*. Scientific journals apply a strict process of so-called peer review. This means that when a scientist submits a manuscript for publication, it is reviewed by a number of (usually anonymous) research colleagues. The manuscript is only accepted for publication if it satisfies stringent demands for scientific quality. Keeping to the scientific literature when assessing the research situation is therefore a way of ascertaining as far as possible that only the best scientific arguments are taken into consideration.

There are two natural objections here. Firstly, the method I am recommending relies on the journals' peer-review system working properly. But what if it is corrupt? Just imagine if the journals and their peerreviewers had simply decided to reject anything that did not support their favourite theories, regardless of whether the arguments put forward were good or bad! This is sometimes claimed and is difficult to disprove, although in the absence of good evidence for such corruption, I believe that we have reason to assume that the system works fairly well. We cannot know for certain that the assertions made in a scientific journal are true (science is not infallible), but these journals are considerably more reliable than other sources that, with a few exceptions, do not have an equivalent system of quality control.

Another objection is that it is difficult or impossible for a layman to follow my advice and determine the state of science based on what is written in scientific journals. Once again, we do not have the time, the energy or the prerequisites to go through the relevant literature. As a result, we are in practice dependent on skilled and reliable researchers summarising what is contained in the journal literature. Hence, the matter of whom we can trust comes up again here, and in the final analysis appears unavoidable. In the next section, however, I will demonstrate how convincing the state of the research is on the issue of anthropogenic global warming.

Scientific consensus on anthropogenic warming

In order to answer whether consensus exists on the climate issue, and how strong and solid it is, we must first specify which climate issue we are referring to. What do we mean when we talk about "the climate science consensus"? Perhaps the most important question is whether it is correct that a) anthropogenic emissions of carbon dioxide tend to contribute to global warming in a way that, in the long term, can be expected to have far-reaching consequences. In the current debate regarding scientific consensus, however, it is more common to refer to the hypothesis b) that these emissions have already caused a considerable part of the warming observed in recent decades.

For the sake of clarity, we need to distinguish between these two theories, as it is fully possible to accept theory a) without necessarily accepting b) as well. In fact, it was precisely this – accepting a) but not b) – that was the dominant view among climate scientists when the climate issue began to climb up the scientific and then the political agenda in the 1970s and 1980s.

When it comes to hypothesis b), that the increase in the Earth's average temperature in recent decades is largely due to anthropogenic carbon dioxide emissions, a study of the scientific literature shows that there has been increasing agreement about this over the past 10–15 years. The fact that this agreement is relatively recent may give some reason to believe that it is not yet completely robust, and that there is therefore reasonable scope for doubt.

As regards theory a) that carbon dioxide emissions in the long-term affect the climate, the situation is different and much more clear. The theory can best be divided up into two sub-theories, namely a1) that human carbon dioxide emissions contribute to a raised carbon dioxide concentration in the atmosphere, and a2) that a raised carbon dioxide concentration in the atmosphere drives global warming via the greenhouse effect. The physical understanding of these two phenomena, a1) and a2), is today very solid, and it is no longer possible to find articles that disassociate themselves from a1) or a2), either in the leading journals *Nature* and *Science*, or in more specialised climate science journals. Both sub-theories also go a long way back in science history.

The notion a1) that our carbon dioxide emissions lead to an increased carbon dioxide concentration in the atmosphere may appear obvious. However, the matter is not quite as simple as it may seem. It was long believed that the oceans could easily absorb almost all the carbon dioxide that was released into the atmosphere. This perception was corrected in the 1950s, however, when the sea's absorption capacity was shown to be more limited, primarily due to the very slow circulation between surface and deep sea. These and other discoveries, together with sound measurement series detailing the change in carbon dioxide concentration in the atmosphere since the end of the 1950s, mean that phenomenon a1) is now beyond all reasonable doubt. Our quantitative understanding of it is also good.

The understanding of the greenhouse effect a2) goes back even further, and is largely a matter of 19th century physics. In the 1890s, the Swedish chemist Svante Arrhenius found a brilliant method for assessing the extent of the greenhouse effect, and we can now establish that his estimate was of a correct order of magnitude. Our knowledge about the greenhouse effect has been consolidated and refined since Arrhenius's days, not least thanks to quantum physics models for molecular radiation absorption.

In summary, it is of course possible to question a1) and a2) (just like all other scientific results), but they are so well established that it would require a scientific revolution of sensational proportions in order to overthrow either of them. As a result, the conclusion a) that anthropogenic carbon dioxide emissions contribute significantly to global warming can be established beyond all reasonable doubt.

Feedback effects and other sources of uncertainty

However, if our understanding of a1) and a2) is now so solid, how can it be that predictions by climate experts are so imprecise? Estimates, under given emissions scenarios, of what the global average temperature will be fifty or a hundred years from now cover intervals spanning several degrees Celsius.

This is due to the many other factors that influence the climate, and the complicated ways in which they interact. Feedback effects, which can have an accelerating effect on warming (positive feedbacks) or a decelerating effect (negative), are of particular interest. We do not fully understand the dynamics of many positive feedbacks. This includes for example how the warming is causing the Siberian tundra to thaw and release greenhouse gases, which in turn drive the warming. Another example is how the reflecting capacity (albedo) decreases when the warming causes the sea ice in the Arctic to melt. More solar radiation is then absorbed, and this leads to continued warming. A third example is how the warming leads to an increased amount of water vapour in the atmosphere, and hence an increased greenhouse effect, as water vapour is a greenhouse gas.

A final approach for those who accept a1) and a2) but still want to downplay the danger of anthropogenic global warming is to maintain that the negative feedbacks dominate the positive ones, and that they do so to such a degree that most of the warming will come to nothing. The American climate researcher Richard Lindzen has speculated in this direction, but the scientific literature as a whole points in the opposite direction.

No dissenters from anthropogenic warming

In case the reader happens to distrust my description of the state of the research, it may be of interest to look at the literature search conducted by the historian of science Naomi Oreskes in the journal *Science* in 2004. She analysed the content of the 928 papers that had been published in peer-reviewed scientific journals during the period 1993–2003 and that include the term “global climate change” among their key words. Oreskes counted how many of the papers disassociated themselves from the scientific consensus opinion regarding anthropogenic global warming. Despite the fact that she chose to interpret this in the narrower sense b) above, she found that out of the 928 papers, there were zero dissenters!

Admittedly, with her keyword search, Oreskes has not captured all the scientific papers about the climate issue from the relevant period, and it is probably possible to find the odd deviating opinion. Nevertheless, her study gives an idea of how much climate scientists agree regarding the theory of anthropogenic global warming.

Oreskes's study is naturally troublesome for those who want to maintain that there is scientific disagreement in this area, and attempts to discredit her have been made. However, if we look at the detailing of papers that are claimed to counter her conclusion (such detailing can be found in works by Benny Peisner and Klaus-Martin Schulte), we see how far they twist what the scientific studies actually say. For example, studies are highlighted that focus on other factors that could drive the climate alongside human influences, such as astronomical factors. There are also papers that argue that the effect on the climate of the increase in carbon dioxide is slightly smaller than others have maintained. The assertion that such results entail an automatic disassociation from the theory of anthropogenic global warming is clearly wrong, regardless of whether it refers to a) or b) above.

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In recent years, he has also devoted much energy to examining various kinds of pseudo-science.

Recommended reading

- Naomi Oreskes. *The scientific consensus on climate change: how do we know we're not wrong?* In the book Climate Change: What it Means for Us, Our Children and Our Grandchildren, MIT Press, Cambridge (http://www.ametsoc.org/atmospolicy/documents/Chapter4.pdf).

This is why we should believe in climate change

The vast majority of us cannot investigate the status of the climate ourselves, and we all know that scientific forecasts of the future are not always accurate. So why should we believe in climate change? The most important reason is that we can rely on science as a process, writes Sverker Sörlin. When this process entails a broad consensus, as now in the climate issue, society has to work on the basis that it is true. It is also risky to postpone measures that could result in reduced warming, whereas there are few known drawbacks.

Sverker Sörlin, Division of History of Science and Technology, Royal Institute of Technology, and the Stockholm Resilience Centre.

Photography: Ulla Montan

Why is climate change such a widely discussed issue? Why does it arouse such strong feelings? Part of the answer is related to the fact that it is not that easy to justify adaptations in living conditions and perhaps restrictions to personal freedom among those of us living on the Earth today, with reference to conditions that could occur in a fairly distant future, particularly as we cannot really see or feel these conditions at the moment. We are talking here about threats and dangers that will creep up on us over decades, generations, perhaps centuries.

What do we know for certain? Why should we subject ourselves to restrictions now for a possible change that is far in the future? Perhaps we are being fooled? If so, it would certainly not be the first time that a long line of experts has predicted that something would happen – which then does not happen at all. Aren't expert forecasts usually wrong? Yes, they often are. Thomas Malthus's extremely pessimistic thoughts in *An Essay on Population* (1798) are the classic example. He believed that people all around the world would live in constant hunger and poverty, and die in large numbers, as the ability to generate prosperity would never be able to keep up with the uncontrollable growth in population.

The difficulties in knowing anything about the future

The vivid visions that were created at the end of the 19th century regarding the form that modern existence would take *In Hundred Years* (1892) – the title of a paper by Charles Richet, French winner of the Nobel Prize for Medicine in 1913 – correspond very little with the world that existed in 1992, and even less with the world of today.

Most assessments of the future meet the same unpropitious destiny. Jules Verne's novels, not to mention those written by Dostoyevsky, come closer to the truth regarding humanity than any researcher could have accomplished. Richet – who went on to become the President of the international society for parapsychology – was wrong with almost all of his predictions. He had no idea about what types of energy would be used, he was wrong about which nations would dominate the world, and of course he did not even know which nations would exist a hundred years later.

The more pretentious and complex the assertions that are made, the more difficult it is unequivocally to confirm them scientifically. If a person states that he knows for certain what the result of an election will be several years in advance, or of a football match that is taking place on the same day, we know that this person cannot cite science to support his claim. This is also why betting firms exist.

However, when a person asserts something about the development of the entire world, he may, paradoxically you might think, have a greater claim to be believed, as long as the assertions relate to science and as long as they relate to something over which man has little influence. As soon as people come into the picture, predictions become difficult, almost impossible. There have been hopes that the opposite would be true. Many have believed, or actually hoped, that the environment would have a decisive influence over social development, but this has proven not to be the case.

Ellsworth Huntington, an American geographer, wrote a large number of books during the first three decades of the 20th century. These were all based on the assertion that the most important driving force behind the development of civilisation is the climate. In cold climates people are creative, warmth corrupts. This idea in itself is an old one; the difference is that Huntington considered he had scientific evidence for it. Environmental and climate deterministic notions could be found in schoolbooks until long into the post-war period. The influence of the environment on individual people is not very much different now than it was a hundred years ago – yet existence for all of us has changed fundamentally. It is difficult for us to imagine that the environment controls the development of political decisions, stock market prices, religion or poetry.

Different time scales

So why should we believe what scientists are now saying about the development of the climate? This book provides a series of arguments for it in many of its chapters. I would just like to provide an additional perspective. At a certain level, the Earth and its surrounding atmosphere can be viewed as a system, the "Earth system" as it is often referred to. This system can be viewed in roughly the same way as chemical liquids in a test tube, and we can anticipate that the system will behave in accordance with the laws of nature.

The system is certainly complicated – far more complicated than anything that can fit in a test tube – with feedbacks, reinforcement effects, accelerations, slips, tipping points and a range of other phenomena that occur at a complex system level, but that do not occur in the same way in simple systems. In principle, however, it should work in the same way. Above all, the system is subject to the laws of nature and is hence comprehensible.

However, as the Earth system cannot be contained in a test tube, and as we cannot perform experiments using the entire planet as a laboratory, scientists instead have to produce models of the system. These models also contain masses of feedbacks, as such a complicated system has many living components that are difficult to predict, and as it contains a self-repairing and creative capability – just think of all the DNA that exists in living organisms.

Timescales are therefore very important. Over millions of years, we can anticipate that the Earth system will change fundamentally; new species will evolve, for example, that can overcome altered conditions. This happens unceasingly throughout the Earth's history, if you have time to wait. But on the timescale that is relevant to us people – i.e. decades and centuries, possibly millennia – nature's creativity does not have time to achieve major adaptations. The only creativity we can really rely on is that of people and society.

We must believe in science

Scientific model designers have consequently come to the conclusion that the Earth's climate will almost certainly become warmer as a consequence of human activity. There are also a great many empirical observations, i.e. observations made in the real world, that support the models. Researchers are equally certain that the warming will generate extremely problematic effects for ecosystems, people and societies, even though these effects will have differing degrees of severity in different parts of the world.

As for those of us who are not specialists regarding these models and who cannot participate in or critically examine the research that lies behind them – what attitude should we take? On one level, there is not a great deal we can do. We have to believe. We live in a society where we have decided to allow science to be responsible for producing the kind of knowledge we can refer to as established, and that we use as a basis for "rational" considerations and decisions.

Anyone who chooses not to believe is naturally fully entitled to his opinion, but cannot expect any understanding. In the worst case scenario, he will appear a fool. Anyone who claims that the theory of evolution is not correct because the Earth was actually created with all the species in place at the one and the same time a few thousand years ago, and that is hasn't changed since then – they are of course welcome to do so, but the rest of us cannot readily entrust that person with any duties within teaching or research in the many subject areas that require scientific knowledge about the development of the world and of life.

Equally, we cannot employ doctors in the healthcare sector who practise homeopathy. They are welcome to try to cure themselves, but not others.

That's just the way it is, or at least how it ought to be. But there is more to be said about this. Because when all is said and done, the attitude described above is fairly arrogant and a little simplified. In actual fact, it is not entirely scientific either.

Because science makes a small but crucial addition: it accepts, it even applauds the idea that there may actually be errors in the current scientific explanation and that there could be a better one. Science has no greater heroes than those who can overthrow established ideas. Anyone who could disprove evolution or, for that matter, show that the theory of global warming was incorrect or at least insufficient, would be given an eternal place of honour in the history of science. We cannot, and should not, completely discount the possibility of this happening. Even though at the moment it obviously appears extremely unlikely.

The knowledge puzzle and archipelago

There is also another factor to take into consideration when adopting an attitude towards scientific theories. How have they developed? A common perception is that scientific theories, or even Truths, emerge from a gradual, step-by-step increase in knowledge. As Newton is supposed to have said: “We are standing on the shoulders of giants”. An individual researcher is certainly small on the Earth, but thanks to the combined knowledge that humanity has amassed, each new generation knows more than the one before it.

However, this striking image hides the fact that the way science builds up combined knowledge and world views is actually considerably more disjointed and fragmentary. It is more like doing a jigsaw puzzle with an infinite number of pieces – without knowing what the final picture is supposed to be. We have put together a considerable amount, but history clearly demonstrates that the puzzle is baffling us. At times we have to tear up certain parts and start making a new picture. We have islands of knowledge about physics, art, anthropology and climate, for example. We also use the same known facts at times to create new pictures, which in turn steer research.

But how do the different parts of the puzzle go together? Are they from the same puzzle? How is thought related to matter? What does music have to do with mathematics? Does taste have anything to do with politics? Can one thing be explained by the other – and if so, which should be the explanatory part and which will have to make do with being explained? Can new knowledge about the history of art in any way affect the understanding of biology – and vice versa? How?

The part that climate plays in the bigger picture is fascinating. The image of the climate's development has changed dramatically since the discovery of the Ice Age in the middle of the 19th century. The picture that we now have began to emerge in earnest just half a century ago. When John Tyndall in 1862 and Svante Arrhenius in 1896 presented their ideas about the greenhouse effect, nobody knew anything about "global warming". The expression did not exist, and we did not know whether the climate was about to become colder or warmer. In a major review of the research prior to the International Geology Congress in Stockholm in 1910, the prominent Swedish researcher Gunnar Andersson wrote that everything was pointing to the notion that the climate in Scandinavia was becoming colder. It was at exactly this time that the climate began to grow warmer …

The fact that warming was taking place, at least in more northerly latitudes, was soon understood, but hardly anybody believed that the cause could be human activity. It took half a century before this perception began to change. It was not until the

1950s that reports started appearing in the media all over the world claiming that the use of fossil fuels could lead to global warming. At this time, the British engineer Guy Stewart Callendar had already launched the idea, in 1938, that global warming – or "climate improvement" as it was described at the time – was taking place, and that the use of fossil fuels was an important cause. In January 1958, the Washington Sunday Star wrote that if carbon dioxide warming proved to be correct, international agreements and draconian punishments would be required that would challenge "our notions of free enterprise".

At the same time, the scientist Charles David Keeling set up his famous measuring station on Hawaii, which would soon begin to demonstrate the steadily rising carbon dioxide graph.

Breakthrough for the carbon dioxide hypothesis

During the 1950s, many scientists grew increasingly convinced that carbon dioxide could contribute to explaining climate change. Before and during the International Geophysical Year in 1957/1958, there were extensive reports in the media about the increasing number of signs of a major change in climate, with melting inland ice, rising sea levels and a future ice-free Arctic. The symbol for this melting in the Arctic, then as now, was the polar bear.

At the same time, usable computers began to appear, and they became increasingly powerful. From the early 1960s, these computers could be used to create models of climate trends that included carbon dioxide as a component. Science investigated a wide range of other factors, such as the ability of the world's seas and forests to absorb carbon dioxide. But there was no doubt that the carbon dioxide concentration in the atmosphere was increasing, and the evidence that it was this component that governed climate change in the long term, over and above the constant natural variations, was growing ever stronger.

A research report to the American Academy of Science in 1979 is generally considered to be the definitive breakthrough for the carbon dioxide hypothesis. This was not the same as knowing for certain that climate change was due to greenhouse gases, but since then this has been the main starting point for established research. In the years that followed, it has been confirmed to an ever greater extent. And it will remain the established scientific position, until somebody can show that it contains serious problems.

However, it is important to bear in mind that this must not necessarily be viewed as the Truth having won through. On the whole, the concept of truth only has a fairly minor place in science. We prefer to talk about what we could refer to as "the best knowledge we can ascertain in the present circumstances". In many areas, such pictures have to be diffuse and incomplete. There may also, with some justification, be competing scientific views for long periods of time, such as how we should look at the causes of mental illness or how much trust we should place in witness testimony from individuals who have been injured or traumatised. In science, too, there are periods of deep controversy regarding central issues. The climate issue has been the subject of such controversies, although this is no longer the case.

Is the climate part of society?

When it comes to the climate, by all accounts, we are now talking about a very stable scientific consensus. This is reminiscent thus far of Darwin's theory of evolution or other theories about the way nature works, which have withstood many tests. However, one characteristic distinguishes the climate models from other scientific theories: man is an important driving force in these models. The principle of evolution is hardly influenced at all by society (it is possible that the direction of evolution is influenced, for example with the aid of breeding or our impact on biodiversity). We can exert even less influence over the force of gravity or the interactions within atomic nuclei. We can utilise these forces, but we cannot influence them.

The climate system, on the other hand, is behaving as it is *precisely because man is affecting it*. How the climate will develop in the future is therefore heavily dependent on how society acts today. There is therefore, on one level, a similarity between the climate models and models of society: they both include the human factor, which we have already highlighted as the factor that baffles scientific predictions.

However, this observation does not say anything about the models' validity or about climate impact up until now – the things that people and society have done in the past are a fact. Nevertheless, this is an important point with a view to the future – unlike many other things that are studied scientifically, the climate is something we can influence. We can make the Earth either warmer or less warm. In the past, all sensible people believed that this was impossible. Environmental historian John R. McNeill, in his fascinating book *Something New Under the Sun*, describes how the American physicist and Nobel Prize winner Robert Millikan stated as late as 1930: "Man cannot do any damage to something as gigantic as the Earth." Millikan was also wrong, just like his Nobel Prize-winning colleague Richet.

And there is another thing: the complexity of the system. This has long baffled science. It has been difficult to establish causal links. From the time it began to become clear that historic climate changes had occurred, even that there had been an Ice Age (discovered in around 1850) and that there had been several ice ages (which became increasingly clear in around 1900) and extensive climate changes even since the most recent Ice Age, scientists began to put forward proposals as to the causes of these changes.

Some years into the 20th century, many still believed that the climate was becoming colder. Many people began to believe this again in the 1960s and 1970s, when there were a series of cold years, in the middle of the overall warming trend that had prevailed throughout the 20th century. In around 1970, when the climate models were beginning to produce their first and, as it would subsequently be shown, fairly credible predictions about the warming of the climate over the next hundred years, there was paradoxically a peak in speculation about an ice age.

This soon subsided. Today, sceptics and deniers have become a small minority of the science community who have been forced on the retreat. However, we do not possess that much systematic knowledge about what characterises this opinion from a sociological and anthropological perspective. Nevertheless, there is much to indicate that these sceptics have a high average age and that they do not always hold positions in those disciplines that are most central to the understanding of the causes of climate change. How do they think and act – and why? More research is required about this, as well as about how the climate-sceptic opinion is formed and maintained in a situation where it is scientifically marginalised.

The climate issue – one part of the environmental account

Why is the global warming theory now so completely dominant? It is not only about science – if it had been, it would have made its breakthrough long ago and already resulted in extensive political mitigation measures. The way the scientific community is organised and has structured its organisations, as well as how it has interacted with political and social institutions, have also been extremely important. The IPCC, for example, is an organisational innovation that has proven to be of great assistance in spreading the carbon dioxide hypothesis and has contributed to its legitimisation, even though it is not the task of the IPCC to give preferential treatment to any particular theory, of course, but instead to work at all times on the basis of scientific consensus.

One important factor behind the transition to consensus on the climate issue in recent decades, however, is the fact that an all-embracing account of environmental impact arose during the 1960s and 1970s, with man in the leading role as the planetary agent of change. This environmental account made it much easier to gain understanding for an anthropogenic (caused by man) explanation for climate change as well, which had now found its way onto the environmental policy agenda. As long as thinking like Robert Millikan – i.e. that people could not influence something as large as the Earth – was perceived as being correct and normal, it was also very difficult to imagine anthropogenic global warming.

In the current world view, where people and society have a decisive influence over the state of nature, the climate sceptics are not only scientifically divergent voices, of course. They also appear as morally reprehensible: the unrepentant who do not want to prescribe the world a tough cure and restore the correct balance between society and Mother Earth. Hardly anyone can maintain such a position in the long term and preserve credibility. The USA's President Bush and his bizarre retinue of unscientific advisors and partisan oil interests succeeded in doing this for a while, but only by virtue of their colossal position of power and at the cost of a considerable loss of reputation in the outside world. This regime, in the world's leading research nation, succeeded for two presidential terms in denying and suppressing insights from an overwhelming majority in the international and the US scientific community. Fortunately, it appears as though this was an exception, and in most countries, including the USA, global warming is now politically accepted.

There is actually only one socially accepted attitude towards global warming, and that is to accept it as a reality. How rapid the adaptation to a society with low carbon dioxide emissions should be, and what methods can achieve this most effectively and most fairly, are still open to debate. Here there is considerable potential for disagreement and countless opportunities to mix science with everything from politics to religion and economics. As regards the actual core issue – whether global warming is occurring and what it is due to – the door is currently closed.

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IMPACTS, ADAPTATION AND VULNERABILITY

When does man's impact on the climate become dangerous?

According to the UN Climate Convention, we must work to prevent dangerous human impact on our climate. But what is "dangerous"? The word is both very precise and troublesomely imprecise, writes Markku Rummukainen. Decisions taken within climate change negotiations and mitigation efforts basically concern what risks we can tolerate and what measures we are prepared to take. Our values have a given role in the debate. Science can in turn shed light on the consequences of various courses of action and what is required to achieve the goals laid down, but it cannot provide us with ultimate answers. Regardless of this, we have to make decisions.

Markku Rummukainen, the Swedish Meteorological and Hydrological Institute (SMHI).

Society's task as regards the climate change is set out in the United Nations Framework Convention on Climate Change. Article 2 of the Convention is central, and states: *"The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."* (United Nations 1992)

To date, 192 countries have signed up to the Convention. There is probably nobody who rejects the task facing the international community. However, "What measures are required and how quickly?" remains open to debate. The Climate Convention does not describe the task in such concrete terms that can underline specific decisions. The word "dangerous" is both very precise and troublesomely imprecise. However, the three important specifications regarding the preservation of ecosystems, guaranteed food production and sustainable economic development put some meat on the bones.

What is dangerous?

It is not possible to determine unambiguously what constitutes dangerous climate impact. Climate changes do not strike democratically. Global warming affects different regions differently. The level of vulnerability also varies within and between communities, sectors and countries. The attitude we take to uncertainties, risks and the fact that climate effects are different in different parts of the world is a matter of values. The potential for changes in the climate system that we do not yet fully understand should probably be viewed as a danger in itself. In contrast, the uncertainty regarding climate changes is instead sometimes used as a reason not to take on the task.

Not all climate changes are dangerous. Relatively small climate effects can even entail some benefit, at least locally. The boundary between non-dangerous and dangerous climate effects can be stretched slightly through adaptations in society, but when the climate changes increase, the opportunities for adaptation will start proving more and more insufficient. Ecosystems in particular should be viewed as vulnerable to climate change, as their resilience is largely unknown.

There are no objective measures for where the boundary between dangerous and non-dangerous climate impact actually runs. Even though many systems ought to be able to withstand certain climate changes, there are also other systems that will be affected at an early stage. How many species should be allowed to disappear before it is considered dangerous? How much may food production or sustainable economic development be allowed to slow down? Values have a given role in the debate, while science helps to narrow down different alternatives.

The two-degree target and tipping points

The two-degree target that the EU countries have adopted represents a concrete form of the climate convention's ultimate goal. The two-degree target refers to a maximum global mean temperature rise of two degrees compared to the pre-industrial era. So far, since that time, the Earth has warmed up just over 0.7 degrees. In other words, we have already gone some of the way towards the figure of two degrees. Emissions made to date will also entail some further warming due to delays in the climate system, which further reduces the distance to the two-degree target. Future emissions will increase the warming even more.

The two-degree target was not internationally recognised until July 2009, when the G8 summit backed it. For some, this goal seems very ambitious. For others the opposite is true, such as for small island nations whose very existence is threatened by rising sea levels. In Europe, the two-degree target is a result of political assessments, with some support from science. Even though this goal would not save us from climate effects, the risks seem to grow significantly for larger global temperature increases. We are talking here about losses of biodiversity, effects on water resources, agricultural production and economic development, as well as risks of extreme weather conditions and risks to human health.

There are also worrying climate effects known as *tipping points*. These are characterised by large, relatively rapid changes in the climate system that could occur after some sensitivity threshold is passed, e.g. a certain degree of warming. A continued rise in global temperature might, for example, drive an irreversible melting of the Greenland ice and continental ice in the Antarctic. Observations in recent years are showing signs that these ice masses are being affected, although it is not possible to establish how close we might be to major changes in these systems.

Emissions, carbon sinks and climate changes

Avoiding climate effects is a matter of reducing emissions of carbon dioxide and other anthropogenic greenhouse gases. In order to ascertain the required pace and extent of sufficient reductions, emissions must be linked to climate changes. This means that we need knowledge about the carbon cycle (how emissions end up in the ocean, the biosphere/land and the atmosphere) and the climate system (which climate changes ensue, where they occur and their extent). We know more or less how emissions, atmospheric concentrations and climate changes are related. However, there are uncertainties about how these links will develop under the influence of continued climate changes.

At present, around half of all anthropogenic carbon dioxide emissions are taken up by the ocean or by the biosphere. This take-up admittedly has effects on ecosystems, but means that only half of the emissions accumulate in the atmosphere. These carbon sinks are climate-dependent, however. A number of studies suggest that they will gradually weaken as the climate becomes warmer. It is possible that ecosystems such as the Amazon rainforests will be wiped out by droughts in the wake of the warming, or that the exchange of carbon dioxide between the atmosphere and the ocean will be altered due to temperature rises or changes in the wind climate. The way carbon sinks are affected by climate change is important in terms of the "allowable emission space" vis-à-vis stabilising the climate. Weakening carbon sinks would mean that more of the emissions stay in the atmosphere compared to stable carbon sinks, and the climate would change more for the same emissions.

The greater the climate sensitivity, the more urgent things become

Climate sensitivity is a measure of how the climate system reacts to more carbon dioxide in the atmosphere. It is defined as the equilibrium global warming that follows a doubling in the atmosphere's carbon dioxide concentration. Climate sensitivity is studied in the light of data regarding ongoing and previous climate changes (paleoclimatology) and with modelling. The answers are in reasonable agreement and together point to values for climate sensitivity of between 2 and 4.5 degrees. The best estimate is considered to be 3 degrees. Slightly lower or higher values for climate sensitivity cannot be ruled out, but they appear to be less likely.

Climate sensitivity is of fundamental importance in decisions regarding the limiting of climate impact and climate effects. The lower it is, the greater the chance we have of achieving a given temperature goal. On the other hand, if the climate sensitivity is high, the need for us to reduce emissions is more urgent.

Stabilisation scenarios help to define climate goals

Climate scenarios are based on possible changes in the carbon dioxide concentration in the atmosphere etc. These changes could be either above or below a doubling of atmospheric carbon dioxide concentration, and the global warming could therefore be more or less than the values mentioned above in conjunction with climate sensitivity. Today's climate scenarios do not usually encompass assumptions about climate policy. Rather, they reflect possible social developments in terms of population, economy and technology. After all, consumption, land use and energy production are driving forces behind emissions. Results which state that the Earth may be between 2 and 7 degrees warmer by the year 2100 compared to the pre-industrial temperature (see figure 3 on page 53) correspond to a range of possible social developments, but without some explicit climate policy. The differences between such scenarios and the desired development illustrate the need for action.

In a less sustainable future and with a continued high level of dependence on fossil fuels, the world is facing a major challenge when the sights are on stabilising the climate. Another insight is that it is unlikely that even a low climate sensitivity together with a "kind" global development with rapid emergence of clean and resource-efficient technology would guide us to the two-degree target without climate policy.

Stabilisation scenarios, on the other hand, relate to futures in which emissions are first limited and then reduced, for example with the aid of specific climate policy, so that the atmosphere's concentration of greenhouse gases does not rise permanently above a certain level. Rather, it stabilises on some level, ultimately leading to a climate stabilisation. Studies of stabilisation scenarios imply technical and socio-economic climate research joining forces with climate modelling. In this context, "economy" often refers to costs associated with emissions reductions. In more complete analyses, consideration is also given to benefits of avoided climate impacts. So far, stabilisation scenarios have been more of an exception than the rule in climate modelling. Still, knowledge about climate sensitivity has provided opportunities to study various stabilisation scenarios on global mean scale (see table on next page).

A stabilisation at 550 ppm carbon dioxide equivalents corresponds to the definition of climate sensitivity, and is consequently associated with an equilibrium global mean temperature rise of about 2–4.5 degrees. It is also possible to deduce the probability of temperature rise at different stabilisation levels.

For example, 450 ppm carbon dioxide equivalents gives a 50 per cent likelihood of achieving the two-degree target. 400 ppm carbon dioxide equivalents increases this likelihood to more than 65 per cent.

Most likely value and very likely uncertainty ranges for the equilibrium global temperature rise (°C) compared with the pre-industrial temperature at various stabilisation levels. (From IPCC 2007)

Carbon dioxide equivalents (ppm)	Best guess (°C)	Uncertainty range (°C)
350	1.0	0.6–1.4
450	2.1	1.4–3.1
550	2.9	1.9–4.4
650	3.6	2.4–5.5
750	4.3	2.8–6.4
1,000	5.5	3.7–8.3

Emissions to date have raised atmospheric greenhouse gas concentrations to approximately 440 ppm carbon dioxide equivalents. However, climate forcing is effectively equal to around 380 ppm, as the anthropogenic supply of small particles produces a cooling effect (see Örjan Gustafsson's chapter). The fact that we have not yet experienced a global temperature rise of a degree or more is due to the climate system's inertia.

The task still has to be made concrete

From a scientific perspective, it is perfectly feasible to stabilise the anthropogenic climate trend over the coming decades, which would limit the risks of serious climate effects. It still remains for the world to agree on how to define this task down to all the details.

The ultimate climate goal should be the same for everyone. The climate, climate impact and possible measures are all global, albeit varying from region to region. In addition to a common responsibility for the climate, it is also in the individual's self-interest to resolve the climate problem. After all, climate changes impact on our access to water, food, biodiversity and vital ecosystem services.

One can well imagine goals that are both more and less ambitious than the two-degree one, that are also reasonably possible to achieve without relying on uncertain future breakthroughs in technical developments or needing to negate continued increases in prosperity in the world. At the same time, of course, there is every reason to continue the research on climate sensitivity and change and impacts, and to examine any set climate policy goals when this is occasioned by new knowledge.

The longer we continue along old tracks, the more distant are the changes that are needed to resolve the climate issue. This is a matter of both knowledge and values. We would not lack solutions, but we need to learn to think in new ways. For example, it is important to phase in efforts aimed at achieving reduced emissions in new investments in e.g. energy systems. The challenge will then soon appear more achievable.

Markku Rummukainen is a climate expert at SMHI, Associate Professor of Meteorology at the University of Helsinki and Adjunct Professor specialising in climate modelling at Lund University. A more detailed presentation can be found on page 81.

Imbalance in ecosystems can accelerate climate change

Climate change has already affected the distributions and annual cycles of many species, disrupting the natural balance within ecosystems. Continued changes might affect ecosystem services and biodiversity in ways that we cannot foresee. Poor countries and regions that have the most to lose may suffer the severest changes. Changes already witnessed are sufficient cause for concern. Terrestrial ecosystems currently absorb over a quarter of anthropogenic carbon dioxide emissions, dampening the increase in greenhouse gas concentrations and mitigating climate change. But this favourable ecosystem service could change abruptly or even reverse, the carbon sinks converting into sources and causing climate change to proceed even more rapidly, writes Benjamin Smith.

Benjamin Smith, Department of Physical Geography & Ecosystems Analysis, Lund University.

Ecosystems comprise the plants, animals, micro-organisms and other living creatures that exist in a particular location, along with their immediate physical environment – the air, water, soil and nutrient solution they interact with and are influenced by. We human beings are very much a part of various ecosystems, or of the global ecosystem. For example, the air we breath is the product of other organisms' exchange of oxygen and carbon dioxide. Our drinking water has usually followed a long pathway through the ecosystem before reaching our wells and reservoirs. We gather food, timber, fibres and various other raw materials from ecosystems both on land and at sea. We are seldom satisfied with the ecosystems that nature provides us with, but shape and reshape them according to our needs – for example in the form of forest plantations, sewage treatment plants and various forms of agriculture.

The diversity of resources and functions that ecosystems provide to human society are sometimes referred to as ecosystem services. They constitute a so fundamental basis for the existence of mankind that they may be regarded as invaluable. Yet attempts have been made to estimate their economic value. One study came to the conclusion that ecosystems throughout the globe provide services worth 33 trillion (thousand billion) dollars per year, with ecosystems on land being responsible for most of this value.

Carbon dioxide storage – an invaluable ecosystem service

One ecosystem service that is particularly widely discussed in the context of climate is the propensity of ecosystems to absorb carbon dioxide (CO_2) from the atmosphere and store it in living biomass and soil (figure 1).

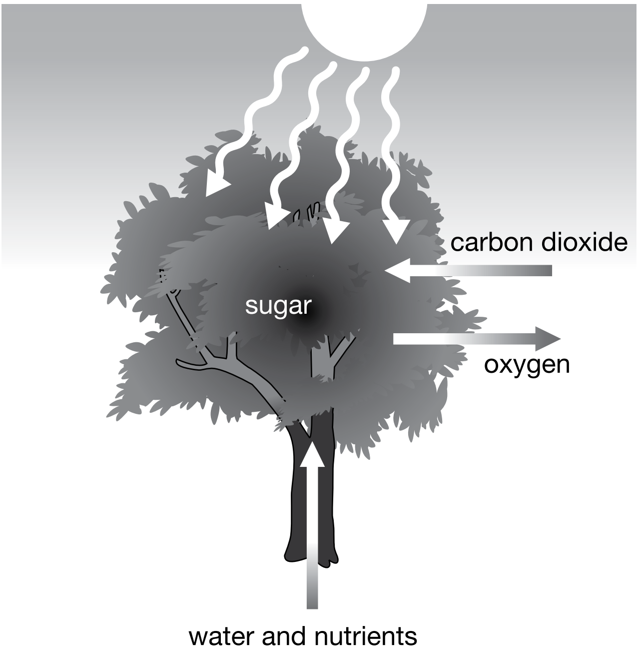


Figure 1. In photosynthesis, carbon dioxide and water are converted into carbohydrates and oxygen. The process is driven by light from the sun. Every year, plants on land absorb carbon dioxide equivalent to approximately 120 billion tonnes of carbon; this is 15 per cent of the carbon content of the atmosphere.

Increased concentrations of carbon dioxide in the atmosphere are assumed to be the primary cause of global warming. The atmosphere currently contains more than 760 billion tonnes of carbon, mostly in the form of carbon dioxide (figure 2). Every year photosynthesis by land plants absorbs carbon dioxide equivalent to approximately 120 billion tonnes of carbon, or 15 per cent of the atmosphere's carbon content. Approximately the same amount of carbon dioxide is released back into the atmosphere through the converse of photosynthesis – respiration, a direct product of the energy-demanding life processes of plants, animals and soil organisms. At present, photosynthesis accounts for some 3 billion tonnes of carbon more than is produced by respiration during an average year. This difference is explained primarily by increased biomass invested in the stems of trees in growing forests.

Anthropogenic emissions of carbon dioxide generate the equivalent of 8 billion tonnes of carbon on an annual average. Of this figure, 6 billion tonnes come from fossil fuel burning and cement production. The remainder is the result mainly of tropical deforestation and the carbon dioxide released to the atmosphere when the timber from the felled trees is burned or transformed into short-cycle forest products such as paper pulp. Three out of these 8 billion

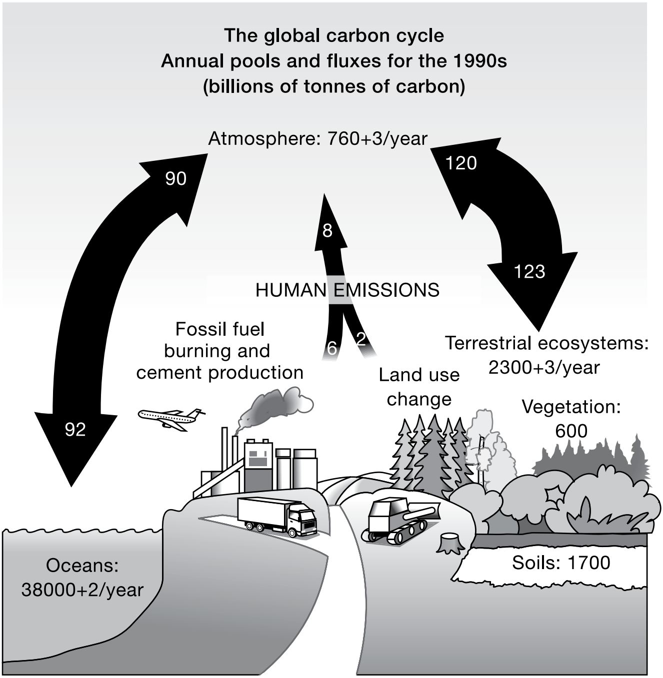


Figure 2. The atmosphere currently contains more than 760 billion tonnes of carbon, mostly in the form of carbon dioxide. Every year, terrestrial plants absorb carbon dioxide equivalent to approximately 120 billion tonnes of carbon, while plants and other organisms jointly emit slightly less than this through respiration and emissions from wildfires. The difference between absorption and emissions is approximately 3 billion tonnes of carbon per year. Annual emissions of carbon dioxide from deforestation and fossil fuel burning amount to 8 billion tonnes of carbon. Of these, terrestrial ecosystems sequester 3 billion tonnes. The oceans sequester around 2 billion tonnes of carbon more than they release each year, also functioning as a sink for carbon dioxide. Three billion additional tonnes of carbon remain in the atmosphere. (Source: IPCC 2007)

tonnes of carbon, then, are sequestered (stored) by land ecosystems. Carbon sequestration is a very valuable ecosystem service. It reduces the increase in the atmosphere's carbon dioxide content and the associated greenhouse effect by a quarter or more, dampening the rate of climate change. Climate negotiators are well aware of the economic and political significance of this particular ecosystem service: to achieve their national emissions reduction targets under the Kyoto Protocol, signatory countries have the right to offset the estimated carbon sequestration of newly-established forests from actual emissions. The forests function as a carbon sink.

The oceans also exchange carbon dioxide with the atmosphere (figure 2). They absorb around 2 billion tonnes of carbon more than they release each year, likewise functioning as a sink for carbon dioxide. Around 40 per cent of the anthropogenic emissions remain in the atmosphere.

Climate impacts on ecosystems

The structure and function of ecosystems is strongly controlled by climate. By structure we mean the composition of the biological community in terms of different species and their abundances, as well as the physical structure – the density and height of a stand of vegetation, the number of layers it comprises, landscape patterns made up of different vegetation elements, and so on.

Function comprises the processes that create and modify structure: photosynthesis, water and nutrient absorption, growth and reproduction, the impact of pests, diseases and predators, competition among individuals and species, and decomposition processes in the soil. Some climate or weather phenomena can have a direct impact on the structure of ecosystems; especially disturbances such as storms, floods and wildfires. More generally, changes in the functioning of ecosystems in response to climate variation will impact on the structure.

Risk for local extinction

The large-scale distribution of most plant and animal species is dependent on climate, especially temperature and water resources. Species that are unable to keep up as climate zones shift or contract may become stranded outside of their "natural" distribution in relation to climate. Local extinction may follow as physiological thresholds for survival are passed, or through competition with other species better adapted to the new local climate conditions. Both of these phenomena may be involved in recent vegetation changes in the southern European Alps, where milder winter temperatures have enabled exotic invaders such as cherry laurel (*Prunus laurocerasus*) to spread into native communities of deciduous trees.

Few species are adapted to disperse at current rates of climate migration in many parts of the world. Moreover, many species are dependent on other species that supply them with food, shelter, a suitable micro-environment, and so on. A compilation of studies from different parts of the world revealed more than a thousand examples of animal and plant species that have already undergone changes that, with some confidence, can be linked to climate warming over the past century. The distribution of many species has shrunk, in some cases to the point that there is no longer sufficient space to maintain a viable population. The downward spiral to extinction may be complex. *Atelopus* is a genus of frogs confined to the rainforests of Central and South America. Two-thirds of the hundred or so species of *Atelopus* have died out in recent decades, as warmer nights and increasing cloud cover have produced optimal conditions for a fungal pathogen that attacks the frogs and weakens or kills them.

Warmth promotes plant production

The world is most likely moving towards a warmer future. Temperatures affect virtually all physical, chemical and thereby biological processes. In general, the rate at which a given process proceeds increases with temperature. As biological systems are built up of many different processes linked to each other at a wide range of temporal and spatial scales, the combined effect of a given change in temperature on the entire system can be complex and difficult to foresee.

Ecosystem scientists have devoted a great deal of effort to investigating the impacts that a warming of a few degrees could have on different kinds of ecosystems. Three main classes of impact can be discerned. In colder regions of the globe, where the annual growing season is limited by low temperatures in the winter, increasing temperatures cause plants to become active a few days or weeks earlier in the spring and possibly to remain active later in the autumn, thereby extending the available period for growth. This results in an increase in plant, or primary, production, which cascades down to other species that are dependent on the plants for their sustenance.

Another important effect of an increase in temperature in a cold climate is that it causes biogeochemical cycles in the soil to speed up. Soils are full of organisms that depend on dead and decaying plant material as their source of energy and nutrients. The most abundant of these are fungi and bacteria, whose metabolism releases organically-bound nitrogen in a process known as mineralization. Mineral nitrogen is an important and often limiting resource for plant growth. When the temperature rises, the populations of micro-organisms and the nitrogen mineralization they perform increase, positively affecting plant production and the activity of the entire ecosystem. The third effect of a rise in temperature is an increase in evaporation, both from the soil surface and the vegetation canopy. In warm and dry climates, increased evaporation can cause the soil to become depleted of moisture more rapidly following rain.

Studies suggest that boreal forests (such as the Scandinavian conifer forest belt, and similar areas in Canada, Alaska and Russia), along with Arctic tundra, will display increased growth and activity in response to a longer growing season and improved nutrition under climate warming. Satellite measurements since the 1980s already reveal a clear trend towards increased "greenness" over much of Eurasia and North America. This is a strong indication that the warming that has already taken place has caused plant activity to increase.

Water-poor areas becoming even drier

When it comes to precipitation, there is less agreement among climate models and scenarios and the trends vary in different parts of the globe. As a broad generalisation, areas characterised by moister conditions in today's climate may be expected to experience increased precipitation, while areas already subject to water deficits and drought may become even drier in the future.

Water is a critical resource for all life. As a result, a trend towards longer or more frequent drought generally constitutes a greater threat to nature and society than a trend towards moister conditions. As temperatures are expected to rise everywhere, the water balance of ecosystems will tend to deteriorate as a result of increased evaporation "sucking" water out of the soil, at the same time as reduced rainfall slows replenishment. Ecosystems threatened by significant reductions in water balance have been identified in the Mediterranean region as well as in Central Asia, the Sahara, southwestern North America and western Australia. The natural vegetation of these areas mainly comprises open forest, savannah (sparse stands of trees or shrubs with a grass understorey), shrubland, steppe and desert. In general, the vegetation in these regions may be expected to become sparser as biomass growth declines. A consequence may be that deserts spread into adjacent areas of bushland or savannah.

Some model studies even indicate that the world's largest continuous tropical rainforest, the Amazon, may be threatened by a dramatic reduction in water balance. In an extreme scenario, parts of the forest could thin out and, in eastern parts of the region, acquire the character of a savannah.

Clouds and aerosols affect solar radiation

Sunshine ultimately governs the dynamics of the entire ecosystem and enables life by supplying the light energy that is converted into chemical energy and biomass in the process of photosynthesis. The amount of energy that reaches the Earth's atmosphere from the sun will not change appreciably over the next hundred years. However, changes in cloud cover and the concentration of airborne particles of various types will affect both the amount and quality of the light that reaches the vegetation.

In general, a clearer sky increases the amount of light reaching the Earth's surface. This favours photosynthesis and hence growth, speeding up the functioning of the entire ecosystem. However, as sunlight also contains wavelengths that tend to warm up the leaves (infrared radiation) and that can damage enzymes and other compounds involved in plant biochemical processes (ultraviolet radiation), haze or light cloud may have a positive effect on plant activity, by dissipating of the strongest rays.

Carbon dioxide promotes growth

When carbon dioxide is discussed in the context of climate change, it is usually in its capacity as a greenhouse gas. However, carbon dioxide is also a vital resource for plants and for entire ecosystems. In photosynthesis, carbon dioxide from the atmosphere and water from the soil are combined with the aid of solar energy to form carbohydrates (sugars), which subsequently serve both as building blocks for new biomass and as an energy source for virtually all biochemical process in plants and the entire ecosystem.

Experiments in which whole ecosystems are subjected to increased carbon dioxide concentrations have shown that growth generally increases by 15–25 per cent for an increase of 200 ppm in the carbon dioxide concentration. This corresponds to the carbon dioxide levels assumed by the lowest emissions scenarios for the end of the 21st century. Some researchers doubt that a growth increase as large as this can be maintained in the long term, taking into account other resources required for growth, such as soil mineral nitrogen.

Models characterise impacts on production and carbon balance

Changes in the structure and function of ecosystems under future scenarios have been investigated using models that describe the key ecosystem components

– primarily the different types of plants, soil organic matter in various stages of decay, and soil fauna. The models simulate how these components respond and interact as temperature, precipitation, incoming sunlight and the carbon dioxide content of the atmosphere change.

Model studies of the global carbon cycle tend to suggest that the relatively strong carbon sinks seen today will decline during the 21st century, becoming sources in some models and scenarios before the end of the century. Global photosynthesis does not decrease, but respiration increases as a consequence of warmer conditions and a larger pool of organic matter in the soil. If respiration becomes greater than photosynthesis on average across the globe, ecosystems will switch from being a sink to a source of carbon dioxide to the atmosphere. This means that the greenhouse effect will increase and climate change may be expected to accelerate!

According to models, the combination of warmer conditions and increased carbon dioxide concentrations will result in increased primary production and growth in many climate zones, which could be positive for ecosystem services associated with agriculture and forestry in these regions. In regions that already experience a warm and dry climate, however, models generally suggest that primary production will decline, as a consequence of a reduction in water balance. Unfortunately, declining harvests will tend to afflict poorer countries, while many wealthy nations may look forward to improved conditions for agricultural and forest production.

Arctic regions may be impacted most

Vegetation models have been used to locate areas in which risks for negative impacts of climate change on biodiversity are large. The models simulate shifts in large-scale vegetation types, or biomes, that can be assumed to reflect the habitats that many different species require for their survival. Sensitive areas turn out to include the savannah areas fringing the tropical rainforest region in Central Africa, the Amazon rainforest and the steppes of Central Asia.

Another way to highlight threats to biodiversity is to look for regions where the existing climate type shrinks or vanishes under scenarios of the future climate. Such an analysis likewise highlights the Amazon and Central Africa as risk areas, along with areas in South East Asia, southern Australia and Siberia. Both biome shifts and shrinking or disappearing climate types tend to coincide with countries that have high species richness and many threatened species. In other words, the greatest changes may be anticipated in regions that have the most to lose from the point of view of global biodiversity!

Cause for concern

Researchers still have a great deal to learn about climate change and its consequences for terrestrial ecosystems. However, studies carried out so far and changes already observed are sufficient to raise serious concern. By absorbing and storing more than a quarter of carbon dioxide emissions from fossil fuel use and deforestation, terrestrial ecosystems are helping to dampen climate change. In the future, however, and as a result of the climate change itself, the global carbon sink could become a source, causing climate change to accelerate.

Climate change over the past few decades has already affected the distribution, function and seasonal cycles of many species, disrupting the natural balance in the biological communities they form. Continued changes may be expected, with impacts on ecosystem services and biodiversity regionally and globally.

Associate Professor Benjamin Smith is an ecologist and climate researcher at Lund University's GeoBiosphere Science Centre. He co-ordinates an interdisciplinary project (financed in part by Formas) developing models to investigate coupled changes in climate, ecosystems and land use across northern Europe over the coming century.

World of Warcraft and ecological crises

Ecosystems are complex – an insight that must determine our handling of the climate challenge. These systems can change rapidly and in such a way that they cannot recover. In addition, the world's various systems in fields such as information, trade, tourism and finance are linked. An event, a disease, an environmental change in one part of the world can cause problems on an entirely different continent. However, a globalised world can also be viewed as our greatest strength. Small innovations namely have the ability to spread rapidly all over the world, writes Victor Galaz.

Orasis Photo/MÅ

Victor Galaz, Stockholm Resilience Centre, Stockholm University.

Terrorists spreading disease, thousands of bodies lying on the ground, entire cities in quarantine. In September 2005, the disease "Corrupted Blood" spread like wildfire in the online game World of Warcraft. What started as an innocent addition to the game to give more advanced players a challenge quickly degenerated into a digital pandemic that paralysed the game for weeks. The disease spread from world to world, from character to character, before the game's developers hit the emergency brake.

This is an extreme case, but it clearly illustrates a number of challenges associated with our ability to manage planet Earth, which is currently undergoing rapid change. And I don't just mean climate change, but also the fact that we are living in a time of overfished and acidified seas, growing megacities, loss of biodiversity and very rapid technical development.

All of these trends are creating a planet whose various parts are not only linked together, but which is also vulnerable to surprises and crises. An event, a disease, an environmental change in one part of the world can cause problems on an entirely different continent. Looking back, it is interesting to note that the first ten years of the third millennium have largely been characterised by crises that have crossed international borders: the September 11 attacks in the USA in

2001, the global SARS epidemic in 2003, the explosive entry of the climate issue onto the political agenda, the interwoven food and energy crisis during 2007 and 2008, the financial crisis and the swine flu pandemic in 2009.

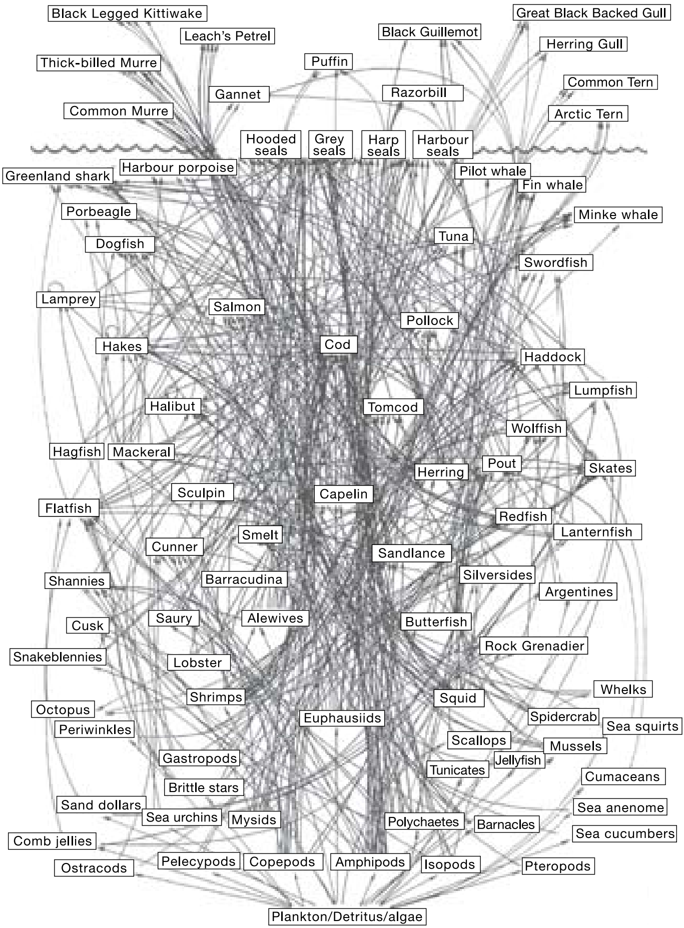
Things we cannot predict

You've no doubt seen them before – graphs, tables and maps painting alternative futures, all of which contain various predictions about how the temperature on Earth will change. The mathematical models that are used to provide support when politicians and authorities have to make decisions have become increasingly sophisticated. We cannot overestimate the importance of this type of knowledge from climate scientists in forcing people and politicians to take the climate issue as seriously as it deserves.

The thing that makes the climate challenge more complicated is that planet Earth's various components and systems are interlinked in a way that we do not really understand. The growth of the information society, international trade, global tourism, international finance flows and ecological changes have all contributed to a connected planet undergoing constant change. Just consider how much of what you eat every day has been produced and packaged in another part of the world. Or how easily people can communicate, share files or play on the Internet, regardless of the physical distance.

These latter trends have caused many scientists to take an interest in trying to understand the properties of *complex adaptive systems*. These systems are characterised by various elements that are linked together, interact and constantly change. Planet Earth is just such a type of system. The sea, air, climate, vegetation, species and people interact – with the result that there is constant change. Some believe that the entire international financial system can be viewed as a complex adaptive system, where flows of money and individual transactions interact in a way that is not only complicated, but that is also difficult to predict exactly. If this assertion feels too vague and academic, just consider the international financial crisis that began in autumn 2008. Or the ongoing development of World of Warcraft with its changeable parallel worlds, constant upgrades and increasingly knowledgeable players.

Ecologists believe that ecosystems, which are the actual foundation for human life on Earth (such as coral reefs, lakes, coastal zones, forests, agricultural landscapes and fish populations), can also be viewed as complex adaptive systems interwoven with human systems. The sea's food web, with cod in the centre, is a good illustration (see figure).



The marine ecosystem can be viewed as a complex adaptive system, i.e. a system in which various elements are connected, interact and are constantly changing. (Source: Prof. David Lavigne, www.visualcomplexity.com)

When we have passed the limit

The realisation that ecosystems are complex is absolutely decisive for the way we handle the climate challenge. Although complex systems can be difficult to predict, there are two things that the research can say for definite. The first is that the systems always bring surprises – events that play out before our eyes but that could not have been predicted in advance, even with the most advanced computer models. The reason for this is that we do not fully understand how all the various parts of an ecosystem, the financial system and human actions are connected. The plant disease black rust (also known as Ug99) is one example. It was discovered in Uganda in 1999, and quickly attacked large areas of wheat fields in the country. When it surprisingly turned up again in 2007 in other East African countries, in Yemen and in northern Sudan, it was uncertain whether, when and how it could spread to Turkey, the Middle East and India. This also occurred in the middle of a global food crisis, when the price of goods such as wheat had gone up very rapidly, leading to hunger and riots on almost every continent.

The other thing we know for sure about complex ecological systems is that they can change rapidly and in such a way that they do not recover to their original state. The system reaches a deadlock. Ecologists have shown that this phenomenon applies for example to coral reefs, which can change from productive, income-earning oases of biodiversity to algae-covered stone landscapes of little value. Other examples include marine systems that can change from clear water to turbid and eutrophicated water, and agricultural landscapes that can change from highly productive ecosystems into dry, low-producing systems.

Several crises at the same time

Another dimension that complicates our ability accurately to predict the effects of climate and ecosystem changes relates to the potential for crises to move from one ecosystem to another and to create not one, but several problems. The link between reduced fishing catches and outbreaks of the infectious disease Ebola in central West Africa is one such example. As fishing resources decrease along the West African coast (due in part to high-tech European fishing fleets), people consider themselves forced to a greater extent to live on “bushmeat”, i.e. apes, bats and other mammals that live in the jungle. Although these mammals represent a good complement to people’s diet, we also know that they are sources of a wide range of diseases that spread between animals and people. Ebola, for example, is a haemorrhagic fever that also has the ability to be passed from person to person, which means that there is always a risk of the disease spreading to larger areas. Bats are not just sources of infection, but also play an important role for forests and agricultural landscapes as pollinators. When bats disappear from a landscape, this means that forest and agriculture can find it more difficult to recover after forest fires or droughts, for example, two phenomena that could increase as a result of climate change.

Ecological crises are consequently far from simple issues, and highlight the interplay that exists between climate change, ecosystem change, political decisions, trade flows and human vulnerability. And anyone who believes that this is only a problem for developing countries is mistaken.

Can technology save us?

A large part of the discussion regarding the climate issue has focused on the potential of technology to reduce our emissions. This discussion is important, but cannot offer a solution to the type of rapidly escalating and sudden ecological crises that I have described above.

Take the threat of increasingly scarce water resources as an example. During a scientific conference in Amsterdam on the theme of "Climate change and water”, the annual Aquatech trade fair, a completely overwhelming exhibition of the latest water technology, was taking place next door. Long lines of gleaming machines and engineers in suits ready to answer all your questions. The contrast to the water challenges in real life could not have been any clearer. Because we already know that it is not the lack of technology that is the main problem. Rather it is the widespread corruption that systematically affects vital water investments in the poorest countries. It is weak states with an occasionally non-existent environmental administration, and local authorities that have neither the resources nor the expertise to implement the necessary reforms. And in particular it is the persistent absence of political will.

Another example is the sudden return of infectious diseases. The disappearing rainforests, increased population pressure, changed climate, weak environmental political institutions and slimmed down healthcare mean that yellow fever and dengue fever have now returned to large parts of Latin America. Technology has little to do with the solution.

I am not opposed to technology, but anyone who is looking for solutions has to realise that they are to be found at the point where technology, politics and ecology meet. During a visit to Stockholm, the

Dutch researcher Chris Reij presented edifying results from his research in Niger, which is one of the poorest countries in the world in one of the driest regions on Earth. The impressive feature is the farmers in the country who, by resuming traditional methods of digging small holes and protecting bare ground against wind and heavy rain with small stone walls, have succeeded in just over twenty years not only in turning the desert green, but have also increased their prosperity and become less vulnerable to drought. This achievement was backed up by co-operation between villages, collaboration between non-governmental organisations and scientists, and national political reforms that safeguard local ownership rights to land and water.

There are also global examples of solutions at meeting points. The World Health Organization (WHO) now receives most of its initial warnings of surprising outbreaks of infectious diseases, such as avian flu, from specially designed search engines that, in the hunt for early warning signs, read everything that is published on the Internet, 24 hours a day, seven days a week and in seven different languages. However, this IT innovation would be pointless if it were not backed up by new international health regulations and a global collaboration between health experts, authorities and non-governmental players.

All tangible solutions to environmental problems on a planet experiencing rapid change must consequently stand on at least three legs: technology, politics and ecological understanding.

Innovations in an interlinked world

There is an old cliché that is worth repeating, namely that innovation and change are born out of crisis. There is a widely held perception that global change is created by political leaders who shake hands in front of CNN's cameras. This is a distorted image. Behind the scenes of ongoing international climate negotiations, it is positively seething with local experiments, innovations and new forms of co-operation. This might involve entirely new ways of managing ecosystems in rapidly growing cities in India, or innovative methods of using mobile phones to carry out financial transactions in Africa – without a developed banking system!

It is these small experiments that have the ability to create positive change, the capacity to solve concrete challenges, to inspire and to spread rapidly around the globe. And this, ironically enough, is precisely *thanks to* the complex web of information, transport, politics and financial flows that is holding the planet together.

A new generation steps up

Many people are surprised that it is not depressing to work with environmental issues, considering the enormous challenges entailed by the climate crisis and global ecosystem changes. I am optimistic, particularly bearing in mind the generation that was born during the 1980s and 1990s. The reason is that we scientists have come to realise that solutions to the major challenges require ever greater inventiveness as well as cross-border collaboration. This cross-border collaboration has proven to be a major challenge for older generations who have grown up in an age when the nation was the natural reference point in a person's life, where communication across borders was expensive and awkward, and where access to scientific information and international news belonged to a few privileged social groups.

This is now all changing very quickly. You will no doubt know more people of different nationalities than your grandparents did in their whole lives. You will understand much more English than Swedes who grew up at the beginning of the 20th century, and you will share and use information in such volumes and with so many individuals that an elderly librarian would gape in amazement. And when this creative generation knocks on the doors of universities, they will be met by a new generation of researchers involved in global multi-disciplinary collaborations, a library with simple and free access to oceans of scientific information, and with students who view co-operation across national borders as something totally natural.

So the parallels between World of Warcraft and ecological crises are not only negative. All those hours spent in front of the computer screen probably have the potential to improve the world after all.

Victor Galaz holds a PhD in political science and is a research theme leader at the Stockholm Resilience Centre. He is currently working on political dimensions of global environmental changes, with particular focus on ecological crises, infectious diseases and information technology innovations. His work is financed by Formas's "Centre of Excellence" venture regarding sustainable development and resilience.

Coral reefs may disappear as oceans turn more acid

Atmospheric temperature has risen more rapidly than sea surface temperature. However, marine ecosystems are not only affected by temperature changes, but also by salinity, acidity and ocean mixing. The sea becomes more acidic as carbon dioxide is dissolved, and this makes it more difficult for organisms to use calcium carbonate to form shells or skeletons. Most coral reefs will probably disappear within thirty years. A positive consequence of climate change is that certain fish species will spread northwards as the climate becomes warmer, writes Keith Brander.

Keith Brander, National Institute of Aquatic Resources, Technical University of Denmark.

Like terrestrial ecosystems, marine ecosystems have seasons and respond to variability in a range of climatic factors. Some of these are the same as terrestrial climate (temperature, wind, light), but some such as salinity and vertical mixing of the water column only apply to aquatic systems. Rainfall (and water supply in general) plays a big role in the way that climate change affects terrestrial biota, but is unimportant in the sea, except where it may influence the salinity and density structure of some coastal and semi-enclosed seas and the run-off of nutrients from land.

Because the density of water is roughly 800 times that of air and the heat storing capacity is much greater, the oceans do not warm up and cool down as quickly as the atmosphere. This means that the difference between day and night temperature is very small in the sea and seasonal differences are also smaller than in the atmosphere, with almost no winter to summer difference at great depths. Nevertheless there are year-to-year changes in ocean climate, particularly in shallow zones, which is where much of the life in the sea is located. The global average sea surface temperature has increased by about 0.4 degrees Celsius since 1980, which is slower than the increase in global air temperature of about 0.7 degrees Celsius.

Positive and negative effects on primary production

As on land, the growth of plants in the sea requires light and nutrients, and the resulting "primary production" is transferred through the food chain to animals and also to bacteria and other microscopic organisms. Most of the plants in the sea are microscopic free-floating phytoplankton which are carried by vertical and horizontal water movements.

Plants are only able to photosynthesise when there is adequate light. Since light is rapidly absorbed in water, this means that production in the sea only happens in the top tens of meters and it depends on the amount of vertical mixing. Some vertical mixing is necessary for the resupply of nutrients from deep water, but too much vertical mixing will carry the phytoplankton down below the light level at which they can use the nutrients in photosynthesis. Climate (winds, heat, other changes in density structure) affects the rate of vertical mixing and therefore the amount of primary production from the world oceans. As surface waters become warmer the density stratification increases, which reduces vertical mixing. Studies of sediments show that plankton production in the North Atlantic declined to about 50 per cent of its present level during past ice ages, due to reduced vertical mixing.

Satellite measurements since the early 1980s show plankton production may have begun to decline in high latitudes, but not in low latitudes and this may be an early indication of climate impact on marine production. One of the few confident predictions we can make about future primary production is that the melting of sea ice, which is taking place very rapidly, will result in greater production, because more light will reach the sea surface.

The sea absorbs more carbon than it gives off

The oceans and their biota are affected by climate, but the oceans also regulate climate in a number of ways, principally because of their capacity for storing heat and carbon. Carbon is absorbed from the atmosphere as carbon dioxide and some of this is taken up and fixed by photosynthesis. When the plankton die they settle to the seabed and build up sediment deposits. Over millions of years the organic material is transformed into fossil fuel deposits (oil and gas) and the calcium carbonate "shells" become limestone.

Without this removal of carbon dioxide from the atmosphere the level of greenhouse gases would be much higher and global warming would occur much more rapidly, so there is a feedback between climate and marine ecosystems.

Acidification damages coral reefs

When carbon dioxide is absorbed in the sea it increases the acidity of seawater which has an effect on the physiology of marine life and in particular on their ability to make shells (which many marine life-forms do). Scientists have only become aware of this problem a few years ago and as yet we do not have much experimental information about the likely consequences, but the effects on coral reefs will be severe.

Coral reefs occur in less than 1 per cent of the oceans, but provide structure and shelter for a vast number of marine species, many of which cannot survive without them. The fish and other biota on coral reefs provide part of the food supply for roughly 100 million people and they are the basis for economically important tourist industries, particularly in developing countries. Recent increases in temperature and decrease in carbonate ion concentration (due to acidification) have already resulted in slower growth of reef-building corals. Extreme temperature events in many parts of the world have caused bleaching of the corals due to mortality of the symbiotic algae living within the coral. At current rates of increase in atmospheric carbon dioxide most tropical reef communities will probably disappear within less than 30 years. The resultant serious loss of biodiversity, fisheries and amenity is one of the most immediate and adverse consequences of global climate change.

There is now a great deal of evidence that climate change is affecting the distribution, species composition, seasonal variations and production of marine ecosystems. I am now going to look at some of the best examples of this.

Krill declining in the Antarctic

Antarctic krill (*Euphausia superba*) are among the most abundant animal species on earth, providing the main food supply for fish, birds and whales. They have declined since 1976, probably due to reduction in winter sea ice extent around the western Antarctic Peninsula. Krill are dependent on the highly productive summer phytoplankton blooms in the area east of the Antarctic Peninsula and south of the Polar Front. Salps, by contrast, which occupy the extensive lower-productivity regions of the Southern Ocean and tolerate warmer water than krill, have increased in abundance.

These changes have had profound effects within the Southern Ocean food web. Penguins, albatrosses, seals and whales have wide foraging ranges but are prone to krill shortage. Thus the wide areal extent of change in krill density – not just its magnitude – is important.

Seasonal variations important for North Sea fishing

The copepod *Calanus finmarchicus*, one of the main zooplankton species of the North Atlantic, has declined throughout most of its range since 1958 due to warming and changes in the extent of cold, deep water masses in which the species overwinters. In the North Sea it has been largely replaced by a very similar southern species *C. helgolandicus*, but there have also been changes in seasonal timing, which affect food web structure and ecosystem functioning. This has consequences for plankton predator species, including fish, whose life cycles are synchronised to the seasonal production of particular prey species.

The survival of young cod in the North Sea appears to depend on the abundance, seasonal timing and size composition of their prey. Changes in all of these since 1958 resulted in increased survival and good recruitment of cod throughout the 1960s and 1970s and then a progressive decline over the past thirty years. One of the main causes of these changes in biological production is varying air pressure and wind over the North Atlantic, which is measured by an index called the North Atlantic Oscillation (NAO). The decline of the European cod stocks due to overfishing has thus been accelerated by climate-induced changes in plankton production and these stocks are no longer able to provide as much surplus for the fishery as in the 1960s and 1970s. As the stocks of cod have declined, they have become more sensitive to the effects of climate, due to shrinkage of the age distribution and geographic extent.

Salinity changes affect the Baltic Sea

Calanus spp. are virtually absent from the Baltic but the copepod *Pseudocalanus acuspes* is a key species and a major food organism for fish larvae and adult plankton eating fish. Large interannual and inter-decadal changes in the hydrographic environment of the Baltic, in particular the decreasing salinity of the deep basins, are thought to be responsible for fluctuations in the abundance of plankton. This has an effect on the diet and condition of herring, resulting in variability in the growth rate of herring between 1977 and 1998. It also affects the stock dynamics of cod in the Baltic. Variability in the seasonal timing and spatial distribution of zooplankton and cod larval production affects survival of cod larvae and subsequent recruitment.

The decadal changes in temperature and salinity in the Baltic, which cause these changes in the fish stocks, can in turn be linked to the regional climate indicators such as the NAO and thus to global climate. However the shallow, complex topography of the Baltic and its entrances and the short timescales of the weather events which drive inflows make it very difficult to predict the frequency of future Baltic inflows.

The marine ecosystems in the Baltic range from those which can tolerate full oceanic salinity to those which tolerate fresh water. The distribution and abundance of several of the major species, such as cod, is sensitive to changes in the salinity. The Baltic is therefore one of the most sensitive major sea areas to climate change. However the sensitivity is due to the salinity rather than to temperature, which illustrates the importance of looking at all the factors affected by climate change and not just temperature.

Plankton and fish spreading northwards

Plankton have been sampled monthly from regular routes of merchant ships and ferries over much of the Northeast Atlantic for the past 50 years. The samples provide one of the most complete and detailed records of changes in distribution and abundance which we have globally. They show very clearly that the distribution of most plankton species has been shifting northward since the 1960's and is now over 1,000 km further north than it was prior to 1960.

We also frequently hear new evidence of the northward spread of fish species along the European shelf appear. The northern limits of a number of tropical and subtropical species have shifted northwards, particularly along the continental slope, at rates (50 km per year) which match the shift in plankton. Detailed records in many areas show increases in populations of southern fish species either in absolute terms or relative to the abundances of similar northern species.

Warming of the North Atlantic in the 1920s

Climate change due to increase in greenhouse gases has only become apparent during the past 30 years or so, but the climate varied before then too and there were cold and warm periods. One of these occurred over much of the North Atlantic from 1920 to 1945 and it provides us with some insight into the changes which can be expected during such warm periods. However the recent human-induced warming is taking us outside the envelope of previous records, so that past analogues will not apply and we are entering unknown conditions. Large-scale distribution shifts in marine ecosystems occurred before there was a human influence on climate and can in this respect be regarded as "natural". The effects of the 1920–45 warming have been extensively described and the excellent literature dating back to the 1930s and 1940s shows how much attention was already being paid to climate effects 65 years ago.

The history of cod stocks at Greenland is a particularly well documented case, which shows how rapidly a species can extend its range (at a rate of 50 km per year) and then decline again. The increase in the cod stock and its northward extension was partly due to greater productivity by the local stocks and partly due to transport of very young fish from Iceland in the surface currents. This gives a huge boost to the cod population at Greenland, but also benefits the Icelandic stock and fishery, because the maturing adults return to spawn at Iceland six or seven years later. The return of the 1945 year class in 1953 represented an increment of 700,000 tonnes of eight-year-old mature fish to the Icelandic stock, worth over 1 billion dollars. Following the decline of the Greenland cod stock due to a combination of overfishing and adverse environmental change in the late 1960s there are quite promising signs of recovery as the environment has once again become favourable for the survival of the juvenile cod supplied from Iceland.

Not all changes are bad

Climate change is already affecting many marine ecosystems and some are likely to be transformed within the next 30 years (including coral reefs and the Baltic Sea). Even with major sustained international efforts to hold back the rate of climate change, many of the alterations to marine systems will probably not be reversible for many decades or centuries. Changes are not always bad and we can already see productive fisheries developing on species such as sea bass and red mullet which have been extending their ranges northward.

However our ability to predict future alterations to marine systems is generally very limited and as we move outside the range of previous conditions there will be unexpected effects. One scenario which is causing concern is that jellyfish may become very much more abundant at the expense of other species, but the basis for this is very uncertain. Careful routine monitoring and the ability to respond rapidly and flexibly to future changes in marine ecosystems are essential.

Keith Brander is senior researcher at the National Institute of Aquatic Resources at the Technical University of Denmark. He is currently conducting research on the impact of climate on fisheries and marine ecosystems. He was the principal author of the fisheries section in the 2007 IPCC report.

Health risks in a warmer climate

More heat waves and more droughts, more serious storms and floods – these are consequences of climate change that can entail direct risks and health effects for people. Indirect health effects might include increased problems for individuals with pollen allergies, as well as the increased spread of infectious diseases, both via insects and animals as well as via food and water. Africa will probably be hit the hardest by climate change, for example in the form of droughts, famines and the spread of malaria, write Bertil Forsberg and Anna-Karin Hurtig.

Bertil Forsberg, Occupational and Environmental Medicine, Umeå University.

Anna-Karin Hurtig, Epidemiology and Public Health Sciences, Umeå University.

There is no doubt that the climate is changing. Risks and health conditions for people will probably be affected in many different ways. This can take place directly as a consequence of changes in extreme temperatures and precipitation, as well as the occurrence of severe storms resulting in damage and death, and indirectly through changes for example in the spread of infectious diseases, the occurrence of certain allergens and increased concentrations of air pollutants.

In some countries, the anticipated impact of climate change on risks and the health situation has already initiated adaptation measures within the healthcare sector, such as warning systems and action plans to deal with heat waves. This is largely due to the very high mortality recorded during the heat wave in Europe in 2003, when the authorities were caught napping and didn't know how to organise efforts for the elderly and susceptible groups. We also need better knowledge and increased awareness in Sweden about how health and the need for prevention and care may be affected by climate change.

Various ways of assessing health consequences

There are several different methods for predicting the health consequences of climate change. We can utilise knowledge about links between climate and health that have emerged from comparisons between different regions, and normal local differences based for example on altitude gradients that affect the climate. The latter include mite allergies in children becoming less common at higher altitudes above sea level due to colder winters with drier indoor climates. The geographic spread of many insect-transmitted infectious diseases is governed by the climate and the ecosystem, even though in practice it is often the material standard that determines whether these diseases become a significant health problem or not.

Another method is to make predictions based on observations of how ill-health is acutely affected by the weather, such as studying how mortality and morbidity are linked to high and low temperatures. As death from cardio-respiratory disease, as well as viral gastroenteritis ("stomach flu") and food poisoning, have a pattern that is influenced by temperature conditions, this can be used to make predictions about what could happen with a different temperature distribution. If storms and floods have already occurred in an area, it is possible to estimate the consequences of storms becoming increasingly common.

Another method is to base assessments on previously documented changes to risk factors or ill health that have occurred in conjunction with changes to the climate, such as more numerous heat waves, the fact that the northwards spread of ticks in Sweden is already taking place, and that the growing period has already been extended so that pollen is present for an increasingly large proportion of the year.

Heat waves can lead to many deaths

The link between extreme temperatures and mortality has long been known. During heat waves, it seems that the impact on mortality can mainly be explained by the heat, although air pollutants such as ozone and particles can also be a contributory factor. The raised mortality in conjunction with cold is considered to be due in part to the cold itself, but also to the fact that viral epidemics break out during the winter months. In most studies, the link between daily temperature and the number of deaths has been observed to be in the shape of a V. Overall, the daily number of deaths appears to be lowest when the average daily temperature is a little over the average annual temperature. The "optimum temperature" therefore varies greatly between different parts of the world, depending on the climate in a particular location and society's and the population's adaptation to the climate conditions. In Norway, the optimum temperature is around 12 degrees Celsius, in London around 20 degrees and in Athens around 25 degrees.

Heat entails different degrees of risk for different individuals, depending on the state of their health. The increase in the number of deaths is greatest among elderly people, in particular elderly women. Ageing entails physiological changes in the body's heat regulation and fluid balance, with the result that elderly people probably do not react as well to the effects of heat. Another important factor is that elderly people suffer more often from diseases that cause particular sensitivity to heat, primarily cardiovascular disease, pulmonary disease and impaired kidney function. Medications that are often used by elderly people can also alter heat regulation, circulation and fluid balance. The majority of heat-related deaths are due to circulatory disorders such as heart failure and blood clots in the heart (heart attack) or in the brain (stroke). The risk of blood clots increases most in people with poor blood vessels and already high blood fat levels.

The heat wave that affected much of Europe in the summer of 2003 had very wide-ranging consequences. In total, it is estimated that there were between 45,000 and 70,000 more deaths than normal during the two-week heat wave. France was affected worst, with increased mortality in all age groups.

Even in a country like Sweden more people die when it is warm. A study of the population of Greater

Stockholm shows that mortality is lowest at an average diurnal temperature of 11–12 degrees Celsius. Above this level, deaths increase by more than one per cent per degree increase in temperature. After several consecutive days with average diurnal temperatures above 22–23 degrees, mortality is raised by around 14 per cent compared to cool summer weather. The effects of heat on mortality in Stockholm appear to have increased in recent times. High air humidity produces a greater increase in the level of risk. If the average summer temperature rises by 4 degrees in Sweden, and the link witnessed in Stockholm is true, it is estimated that there could be around a thousand additional heat-related deaths per year. Greater variability in temperature (more extreme temperatures) and adaptation measures could influence this situation, however.

Allergens and air pollutants

Botanists and pollen scientists have noticed the change in climate in recent decades, after measuring increasingly early starts to the pollen season and increasingly long seasons. The warmer climate is also leading to new pollen-producing plants becoming established further to the north, and to certain allergen-producing grasses and deciduous trees extending their range. Scientists have also shown that pollen production increases with an increased carbon dioxide concentration, and that higher temperatures increase the amount of allergens. Allergies are common in countries such as Sweden, and climate change may result in individuals with pollen allergies being affected for longer periods. Allergen exposure is also important for the risk of developing allergic rhinitis and asthma.

Increased precipitation and more flooding can make water-damaged houses more common, which can increase people's exposure to substances from water-damaged materials and to mould spores. Mould allergy is uncommon, admittedly, but the risk of asthma and respiratory problems is significantly raised in water-damaged houses and could be related to other substances.

Asthma in children in mild climates is often associated with mite allergies. In northern Scandinavia and at higher altitudes, the winters are so cold that air humidity indoors in heated areas in the winter is very low. Mites cannot survive cold and dry indoor environments, which is why allergies to house-dust mites are very seldom seen in such locations. In Western Europe, the occurrence of asthma in children is higher the higher the average relative humidity of the indoor air, whereas high altitudes and large temperature differences between summer and winter result in a lower risk of asthma. With winters that are a few degrees milder, the occurrence of mites will extend to new regions, which could result in more individuals developing this allergy.

Changes in the climate may affect the air pollution situation. Higher temperatures accelerate many chemical reactions in the atmosphere, such as ozone formation. In addition, the evaporation of volatile substances increases. Where climate change is mainly expected to result in higher temperatures and drought, such as in southern Europe, the formation of ozone and particles is expected to increase. These pollutants have a well-documented negative effect on people, and can influence morbidity and mortality in both the short and the long term. Drought may also increase the spread of particles from dry areas, as well as emissions of soot and gases from forest fires. On the other hand, milder winters may reduce heating requirements and hence emissions. Similarly, areas that receive more rain may benefit from pollutants being "washed out" of the air. All in all, the effects on the air are difficult to assess.

Spread of infection through water and food

Floods and increased water flows can lead to pathogenic organisms that live in the soil finding their way into drinking water. In many parts of the world there have been increasing outbreaks of diarrhoea shortly after heavy rainfall. Extreme weather events will also increase the risk of floods and disruptions to sewage treatment works, resulting in pathogenic organisms or harmful substances ending up in the water mains network.

Increased temperatures can result in increased bacterial growth and impaired drinking water quality. They can also lead to bathing water being affected. In recent years, a number of cases of bath-wound fever have been documented; this infection, which is caused by aquatic bacteria, can be fatal for susceptible individuals.

Food poisoning is relatively common. The elderly, small children and individuals who are already suffering from another illness are particularly susceptible. Food poisoning can become more common in increased temperatures. The way the food is handled is important. Incorrect refrigeration, insufficient cooking or heating are common causes of food poisoning. Altered behaviour in warmer weather also increases the instances of food poisoning, such as cooking food outdoors, eating more salads and eating out in the countryside.

Will malaria return to Europe?

Temperature increases may result in tropical diseases affecting Europe. Some tropical diseases that are spread by mosquitoes have turned up in Europe, such as outbreaks of chikungunya fever in Italy. Infections of this type are still uncommon, but it is important to have a good monitoring system in place so that measures can be implemented quickly to impede outbreaks.

Many people wonder whether climate change will result in malaria returning to Europe. No definitive conclusions have been reached, although it is unlikely that we will experience problems with malaria in Sweden. We already have mosquitoes that could spread malaria, and with increased temperatures there will be more mosquitoes for longer periods. In order for malaria to gain a foothold, however, it is necessary for the malaria parasite to be transmitted from people to new mosquitoes. The factor that argues against malaria becoming a problem in Sweden is that it will be difficult for the mosquitoes to find infected blood when they bite. Those cases of malaria that arise will probably be detected and treated quickly.

Diseases from ticks and rodents

In Europe, the tick *Ixodes ricinus* is the primary carrier of two infections that affect people, namely borreliosis

(Lyme disease) and tick-borne encephalitis (TBE). This tick is spreading northwards in Sweden along the Baltic coast, and is expected to spread in the province of Norrland, apart from the mountainous regions. It has been discovered that the increased number of cases of TBE in the Stockholm region since the mid-1980s is linked to the milder, shorter winters during this period. In areas where TBE has spread, vaccination is recommended.

In the case of Lyme disease, symptoms are reported in the skin, the central nervous system, heart and joints. Small rodents are common reservoir hosts. The tick sucks blood from small rodents, thereby becoming infected, and can then transfer the infection to people. In Sweden there are around 10,000 cases in people each year. There is no vaccine, although the infection can be treated with antibiotics.

In the county of Västerbotten, there has been a significant increase in Nephropathia epidemica in recent years, probably caused by the mild winters and increased occurrence of the bank vole. The infection is transferred from bank voles to man, either through the inhalation of dust particles that have been contaminated by the vole's secretions or via other contact with material infected with the virus. The majority of those infected believe they have contracted the infection during activities in woodsheds and other outhouses, as well as in dwellings. Nephropathia epidemica can produce a high fever, stomach pains and affect the kidneys. The treatment is targeted at the symptoms.

In a warmer climate, we can anticipate problems in the form of a greater number of insects. In our northerly latitudes, bees, wasps and horse flies can become particularly problematic. Allergic reactions to wasp and bee stings can have serious consequences, as sensitivity increases with increased exposure.

The poorest countries are affected worst

In rich countries, with our developed infrastructure, we are in a relatively good position to meet the increased demands associated with adaptation to climate change. The situation is not as good in many other parts of the world. Many of the world's countries have a poor capacity to adapt and will be vulnerable. Africa is considered to be the region that will be affected most. Scientists are predicting reduced precipitation in large parts of the continent over the next hundred years. This shortage of water is expected to affect 600 million Africans by 2050 (compared to the current figure of around 200 million). This will impact on local food production, with increased malnutrition as a consequence. Malaria and other infections will probably increase and spread to new areas.

Large parts of Asia will be affected. Glacial melting in the Himalayas may result in more flooding and landslides in the short term. In the longer term, reduced access to fresh water is anticipated. Low-lying coastal areas such as those in Bangladesh, Burma and Cambodia will be affected by rising sea levels and more storms. Increased temperatures and more heat waves may increase mortality in Asia's rapidly growing elderly population, particularly poor people in the major cities.

Climate change in combination with rapid population growth and urbanisation could result in conflicts and increased flows of refugees. Even though it is anticipated that neighbouring regions will receive the majority of these potential "climate refugees", some can be expected to try to get to Europe. Effective aid work that takes the various aspects of climate change into consideration may result in the risk of environment-related conflicts diminishing and the need for emergency disaster aid being limited.

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Managing water to meet both food and bioenergy demands

The share of bioenergy in the energy mix should increase in order to reduce emissions of greenhouse gases. At the same time, demand for food and other agricultural commodities is growing, and further competition can arise for limited resources such as land and water. Water stress and scarcity already represent a significant development impediment in many places, and when the climate changes this situation may be exacerbated. It will be necessary to use water more effectively in order to increase the amount of biomass produced and utilised per unit of water. Considerable improvements are possible and demand for bioenergy is opening the door to new opportunities, write Göran Berndes, Louise Karlberg and Jan Lundqvist.

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The consequences of climate change for agriculture will vary between different regions of the world. Studies indicate that many developing countries, where the capacity to adapt is the lowest, may be greatly affected by both droughts and flooding. An increase in sea level and flooding caused by storms can also cause major damage as a result of sea water flooding the land and seriously restricting access to fresh water.

A third of the world's cultivated land is less than five metres above sea level. The glaciers in the Himalayas – from which the major Asian rivers receive their water during the dry months of the year – may disappear, which would have serious consequences for the irrigated agriculture in the region. Other areas may also be affected by a decline in the water supply from glaciers, such as the west coast of the USA, which receives a large proportion of its water from glaciers in the Rocky Mountains and the Sierra Nevada. There is still considerable uncertainty about the way in which important factors such as temperature and precipitation patterns will change in various parts of the world, but there is no doubt that altered access to water can have a dramatic impact on the conditions for agriculture.

At the same time, the pressure on agriculture is expected to increase significantly, both through increased demand as a result of a growing and increasingly wealthy global population, and through the expected increase in demand for bioenergy in line with greater demands to cut back on the use of fossil fuels in order to reduce the climate impact from society. In addition, energy security concerns related to the geographical distribution of oil and gas reserves, which are also limited, have resulted in biofuels being promoted as an alternative transport fuel in many countries.

Competition and synergies between food and bioenergy

A widely debated issue in recent times relates to the competitive situation between the production of food and bioenergy. When food prices rise rapidly, vulnerable groups in various parts of the world are greatly affected. The nature of the links between increased bioenergy production and rising food prices is disputed, but we are still justified in asking the following question: Can bioenergy play a significant role without endangering food safety? And what consequences might an expansion of both food and bioenergy production have regarding the sustainability of other ecosystems? At least as important, although seldom expressed, is the question: How can we, through an altered diet and better economising, reduce the pressure and alleviate the future impact from agriculture?

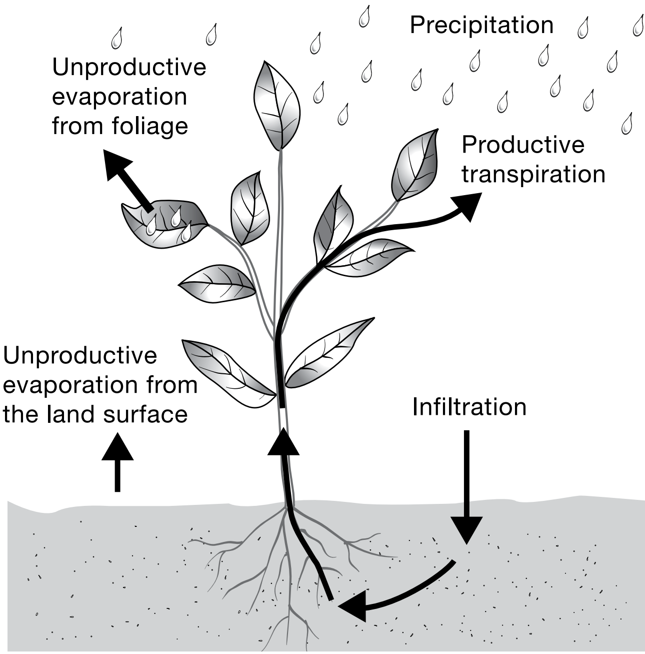
We will describe various strategies for meeting the increasing demand for food and bioenergy. The account uses a water perspective as its starting point and is also relevant for example for the discussion about carbon sinks, where for instance forests are being established to sequester atmospheric carbon dioxide. In the same way as expanded bioenergy and food production, forestation also entails altered demands for water in relation to previous land use, which in turn affects surrounding ecosystems. In general it can be said that if fields, pastures or natural ecosystems comprising sparse vegetation are forested, the consumption of water will probably increase as a result of the plants taking up more water, which is lost to the atmosphere via transpiration through the leaves' stomata. This can result in an even more pressed situation in areas that are already characterised by water shortages. At the same time, forestation – or the establishment of energy plantations and other types of vegetation – can lead to positive effects such as reduced erosion if carried out in a well thought-out manner.

Land use strategies must naturally also be viewed in a socioeconomic context. Biomass production – for food, bioenergy and other purposes – is developed as a response to demand, and the world's farmers will therefore not choose in the first instance to produce what is best purely from a water perspective.

Water and plants

The water cycle is driven by the sun and is a precondition for a great many functions on which people, animals and plants are completely dependent. The total amount of precipitation that falls over land amounts on average to around 110,000 cubic kilometres per year. Of this, around 70,000 cubic kilometres are returned to the atmosphere each year through evaporation from the land, foliage, lakes and watercourses, as well as through the plants' transpiration (figure on next page). The way in which the water is returned to the atmosphere is determined both by climate factors such as temperature and air humidity, as well as by the nature of the land and the vegetation. The remaining 40,000 cubic kilometres of water per year forms surface runoff or drains down into the groundwater. It continues through the landscape in lakes and watercourses, before finally reaching the sea.

Transpiration is the actual basis for the production of both food and bioenergy. The water that is taken up by the plants and passes through their vascular systems can then be used in photosynthesis in the green parts of the plants. Energy-rich substances are formed out of water and carbon dioxide, with the aid of energy from the sun. The water that is taken up from the ground also causes the plant's cells to be held taught, with the result that the plant does not wither. When the water in the vessels reaches the plant's stomata, it evaporates, and this is the actual transpiration process. Transpiration creates a partial vacuum in the plant's vessels, which makes the roots take up more water out of the ground.



The water that is infiltrated in the ground can be taken up by the plant and pass through its vascular system. Some of the water is used in photosynthesis. Another part is emitted from the leaves' stomata through transpiration and helps to maintain the suction for more water from the ground. Some of the water evaporates directly from the ground and foliage and does not contribute to the production in the plant.

Around a quarter of all evaporation and transpiration from land areas takes place from agricultural land, i.e. land that is cultivated for food and animal fodder as well as pasture, although there are considerable variations between different countries. Most of this water is rainwater that has fallen over agricultural land, although a significant proportion is also surface runoff or groundwater that is diverted from rivers or lakes or pumped up from the groundwater and used for irrigation.

Strategies for more efficient water use

From a water perspective, it is possible to increase production of food, bioenergy and other biomass-based products by:

- expanding cultivation and pasture land and/or increase irrigation within agriculture (increased water demand)
- investing in farming methods that make it possible for some of the water that evaporates from the ground and foliage instead to be returned to the atmosphere through plant transpiration; this contributes to "more crop per drop" without necessarily leading to increased overall water consumption (increased water productivity)
- refining the produced biomass more efficiently into food, bioenergy or other products that can also be utilised more efficiently, for example through

cascade use, where e.g. trees can first be used to produce paper, which is then reused before finally being employed for energy purposes (increased efficiency).

The strategies entail that we have to balance the value of increased production, the cost of achieving the increased production (through increased biomass production or more efficient utilisation of the already produced biomass) and the impact on surrounding ecosystems to which the various strategies give rise.

When natural ecosystems become agricultural land

From a purely biophysical perspective, the conditions still allow for expansion of agriculture land in certain runoff areas. This spatial expansion can drastically alter (both increase and decrease) access to water in other parts of the landscape, particularly in downstream areas. In many parts of the world, the ongoing area expansion is taking place at the expense of natural ecosystems with a high biodiversity, ecosystems that also maintain other important ecosystem services. One example is the gradual conversion of Brazil's rainforest and the species-rich savannah (*cerrado*) into agricultural land. Another example is the expansion of oil palm plantations in Southeast Asia, which in many places has resulted in extensive loss of rainforests.

In addition to the biodiversity losses that are associated with the conversion of natural ecosystems, such expansion of agriculture can also lead to large carbon dioxide emissions. Forests in particular contain large amounts of carbon bound in the soil and biomass, carbon that is largely emitted as carbon dioxide when the land is converted.

More water is utilised through spatial expansion. More water can also be used for biomass production as a result of more surface runoff or groundwater being used for irrigation within agriculture. Many countries already implement the large-scale transport of water from one runoff area to another, and new mega-projects are being discussed or are in progress, for example in India and China. By drilling wells, building dams and redistributing water between geographically separate areas, we can utilise water to some extent that would otherwise not be available because it is located far from the cultivation areas, is only available outside of the growing season or is simply lost in the form of large flows during rainy periods.

In many countries, however, strategies that focus on utilising runoff or groundwater flows have become increasingly controversial and expensive in financial, social and environmental terms. Dams and the large-scale removal of surface and groundwater endanger the sustainability of aquatic and terrestrial ecosystems, and can cause problems as regards the transport of sediment, dilution and temperature regulation. It can also lead to falling groundwater levels which, in the long term, can result in penetration by salt water.

“Harvesting” rainwater

One potentially important solution is to capture surface runoff locally, for example in small dams (*rainwater harvesting, RWH*), which can be used for irrigation. Solutions of this type are most relevant for tropical areas where the precipitation often falls as immense cloudbursts, and where dry periods lasting from a few days to several weeks often occur during the rainy season. These dry periods currently cause extensive reductions in harvest and, in the worst cases, crop failures. As the frequency of these dry periods is expected to increase in an altered climate, measures of this type will become increasingly important.

In addition to bridging dry periods, RWH strategies can also limit erosion and reduce sedimentation in rivers and lakes. However, large-scale development in some areas could have negative effects in the form of reduced access to water downstream. More research is required here in order better to understand the links between upstream RWH strategies and downstream access to water – in order to weigh up the advantages upstream against the disadvantages downstream in development strategies.

Reduce unproductive evaporation!

It is impossible to specify absolute limits for our utilisation of surface runoff and groundwater flows, not least due to uncertainties regarding the impact that climate change will have. However, estimates enable us to state that, at a global level, we already make use of more than half of what may be available within the framework of sustainable water use, and that there is already a shortage of water in several regions. This means that the potential for increased biomass production based on increased water extraction is relatively limited.

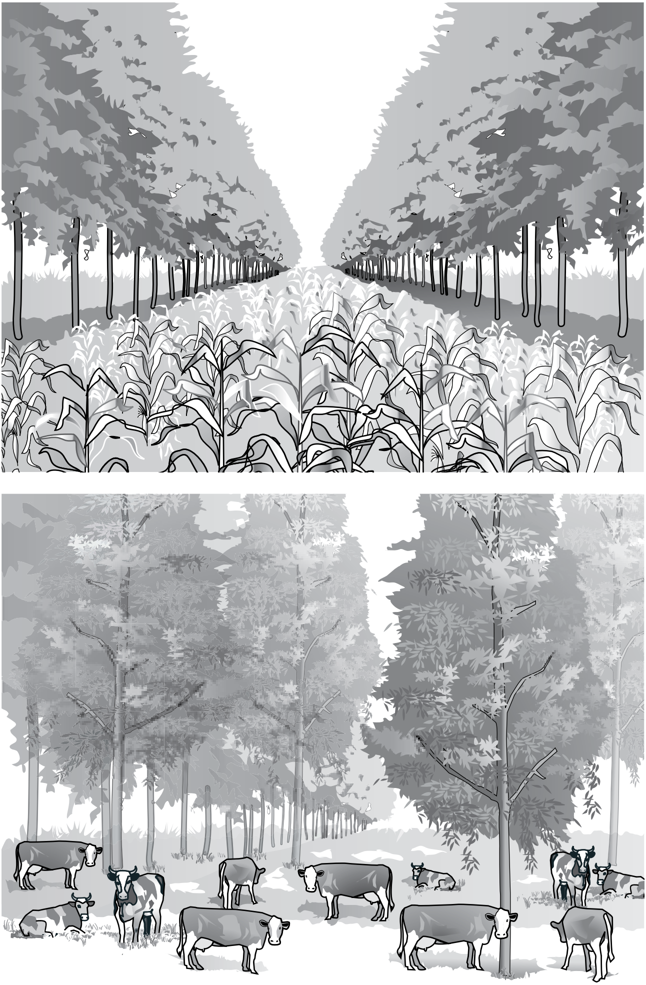
Improved water productivity within agriculture can significantly mitigate the increase in water requirements for food production. Water productivity refers to the relationship between the amount of biomass that is produced and the amount of water that is consumed (transpired and evaporated) during production. Barely half, and sometimes considerably less, of the water that returns to the atmosphere from the agricultural system is currently used productively, i.e. via the plants' transpiration, although there are large regional variations. By increasing the proportion that is utilised in transpiration, we can improve the system's water productivity. We can achieve this through a range of management methods, such as covering the ground, different ground preparation methods, protective irrigation, fertilising and, not least, through land use that entails a denser layer of vegetation, which shades the soil and hence reduces evaporation from the ground.

It is important, as far as possible, to increase productive transpiration *at the expense* of unproductive evaporation from the ground and from foliage, as this makes it possible to produce more without necessarily reducing access to water for other users or areas downstream. If a significant proportion of the increased transpiration takes place at the expense of downstream water access, there is a risk that the gains made from increased upstream production will be cancelled out by reduced downstream production. An example of this is South Africa, where negative experiences from upstream forestation projects have recently resulted in a requirement to obtain a water usage permit before new forest plantations may be established.

New crops and integrated cultivation increases water productivity

The increasing demand for bioenergy does not only mean an increased burden on already heavily strained water resources, but also new opportunities. At present, conventional agricultural crops are used for producing biofuels for the transport sector, but in the long term it is anticipated that lignocellulose will constitute the primary bioenergy raw material, both for power and heat production and for the production of biofuels for transport. As a result, the production of new types of crop will be of interest. Many of the crops that may be used for bioenergy are perennial and have longer growing seasons than traditional agricultural crops. A well developed layer of vegetation for a larger proportion of the year means that more of the annual precipitation can be channelled into the plants' transpiration. By integrating bioenergy crops with traditional agricultural crops and with pasture, it is possible to achieve major improvements in overall water productivity.

At the same time, the total water evapotranspiration (i.e. the sum of evaporation and transpiration) within the system may of course increase, which could result in water-related problems in downstream areas. However, there are extensive areas of degraded land or extensively utilised pastureland, and it should be possible to grow energy crops on some of this land without such problems arising.



Water productivity can be improved by means of energy crops being integrated with maize cultivation or pasture, for example. The examples have been taken from Brazil.

Water-smart consumption

Improved economic conditions and changed living conditions have resulted in drastic changes to food consumption patterns. The opening question, i.e. whether this development can continue if we are also going to produce biomass for energy, is extremely relevant. The answer to this question should be sought over a broad perspective covering the entire chain, from the production of biomass to final consumption. An important question is how the biomass that is produced can be converted more efficiently into food, bioenergy and other products – and also utilised more efficiently. Just as we are now starting to become familiar with the concept of climate-smart consumption, we can talk about water-smart consumption, i.e. consumption with high water efficiency.

There is a significant difference between what is produced in the field, what is available in the stores (supply at market level) and the actual food intake, i.e. how much we eat. More studies are required here, although those that exist indicate that around half of the food that is in the farmers' fields is lost in the food chain in various ways. Wastage in the field as well as during transport and storage is a major problem in poor countries with a warm, moist climate. The food that disappears or is discarded has also required water and other resources to produce. A more efficient food chain with smaller losses could improve our potential to meet the future demand for food while also leaving room for bioenergy as well as natural ecosystems.

Another major opportunity lies in utilising organic waste and residual products for bioenergy purposes. This means that biomass, whose production has already used water, is utilised better and as a result the overall water productivity can be significantly improved. Once again it is necessary to manage competing demands. Waste products are used for other purposes, such as animal fodder and caring for the land; some harvest residue must be left behind in order to preserve the fertility of the arable land. However, model-based analyses indicate that extensive bioenergy production could be based on the sustainable utilisation of these residual product flows. If we were also to utilise some of the residual product flows within the forest sector and organic consumer waste, it is possible that in the region of 50–100 exajoules (EJ, 1 EJ = 10^{18} joules) of biomass would be available by around 2030. This can be compared with the global oil consumption in 2005 of around 160 EJ.

Important issues for the future

There are many important questions still to be answered, such as how we can manage rapidly increasing demand for food, which is very demanding as regards water, land area and resources, and which also entails large emissions of greenhouse gases. This applies in particular to meat production, particularly beef; in global terms, these greenhouse gas emissions are on a par with emissions from the transport sector. Calculated in terms of the energy content of food, meat production requires an average of eight times as much energy as vegetables, although there are considerable differences between different types of meat.

Other questions that will need to be answered in future development strategies are:

- Where can biomass production for energy purposes expand, and what will the consequences be for access to water in downstream areas?
- How are the water flows in the entire runoff areas affected by altered land use and management, and what does this mean for the sustainability of the ecosystems and the living conditions for people locally?

If our consumption of biomass could be made more water-smart, there would be more room for all three: food, bioenergy and natural ecosystems. But how can incentives be generated to stimulate water-smart consumption? There is a considerable need here for user-friendly decision-making support systems that can both illustrate the consequences of various land use and management alternatives, as well as help consumers and decision-makers to identify potential conflicts and see the need for new policies within these areas.

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Louise Karlberg works as a researcher at the Stockholm Environment Institute and the Stockholm Resilience Centre. She works primarily in the field of ecohydrology, which incorporates the study of water's functions and flows in ecosystems.

Jan Lundqvist works at the Stockholm International Water Institute, where he is the Chair of the Scientific Programme Committee. He has worked extensively with water and development issues in various parts of Africa, Asia and the Middle East, including within the framework of a Formas-funded project regarding allocation closure of water resources in southern India.

Recommended reading

- *Water for food*, Formas 2008 (www.formas.se).
- *Multifunctional bioenergy systems*. The AGS Pathways Report 2007:EU1. The Alliance for Global Sustainability (www.agschalmers.se/publications.html).
- Göran Berndes, Julia Hansson and Stefan Wirsenius. *Biomass – a scarce resource from a global perspective*, in the pocketbook "Bioenergy – for what and how much?" (www.formasfokuserar.se)

Biofuels with multiple benefits – the case of Jatropha in Zambia

Increased production of modern biofuels in developing countries can reduce poverty and alleviate the impact on the climate. However, it is necessary to select crops that are adapted to the ecological and social conditions. In Zambia, it has been determined that the bush *Jatropha curcas* is the most suitable crop for the production of biodiesel. Jatropha can also supply a number of other products, while also contributing to reduced deforestation, improved soil and rural development, write Francis X. Johnson and Thomson Sinkala.

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Thomson Sinkala,
University of Zambia.

In recent years, bioenergy has emerged as an important element in the transition to sustainable energy in both industrialised and developing countries. Bioenergy is the only category of renewable energy sources that is continuously available, and it is also the only one that can provide energy in all forms and energy carriers – heat, electricity, mechanical energy, gas and liquid fuels. Bioenergy has another advantage, in that it can contribute to the better development of agriculture and improve damaged soil that is not suitable for food production.

At the same time, the large-scale expansion of bioenergy – and in particular liquid biofuels – entails a range of environmental and social challenges, such as competition with food crops, the exclusion of small farmers and land degradation. Bioenergy stores carbon and reduces carbon dioxide emissions compared to fossil fuels. However, when forests or other carbon-rich land areas are cleared to facilitate bioenergy cultivation, this can actually entail a net loss as regards greenhouse gases rather than a net gain, depending on the type of land in question and the time horizon that is selected.

In order to avoid such problems, it is necessary to select crops that suit the ecological and social conditions in the region in question. In tropical and subtropical climates, sugar cane and oil palm are the most productive biofuel crops, in technical terms. However, as these crops are grown in monocultures under particular climate conditions, there is increased interest in other alternatives that may not be so technically advanced, but that have strong social and/or environmental benefits. Crops that produce a number of other products and services in addition to energy are particularly attractive in developing countries, where by-products can replace expensive imports and/or improve health and quality of life in rural areas.

Once such example is *Jatropha curcas*, an oil crop that can grow in a large number of tropical and subtropical climates and that produces many by-products that are often valuable for the countryside. We focus on the use of Jatropha in Zambia, and show how small family farms can benefit from its cultivation. We also discuss Jatropha from a national perspective as part of Zambia's energy policy and biofuel strategy.

Zambia's energy policy and biofuel strategies

Zambia is a small country in southern Africa. Even though it is a very poor country, the agricultural conditions are good and there is sufficient high-quality land to feed its own citizens. The country is only a net importer of food during droughts. Zambia is a land-locked country and has a low population density. For this reason, transport and infrastructure entail considerable costs and have a significant impact on socioeconomic development in the country. The reliability of the fuel supplies is therefore just as important an issue as the supply of food, as farmers and small companies struggle to bring their products to markets and distribution centres.

In November 2007, the Zambian government introduced an energy policy that includes biofuels, and it is expected to become mandatory to blend biofuels with petrol and diesel. The Zambian government also realises the need to reduce emissions of greenhouse gases and has signed up to the Kyoto Protocol. Zambia has developed a policy for utilising its potential as a producer of renewable fuels and facilitating the growth of a biofuels industry in order to make a positive contribution to the Zambian economy. This framework has created a market in Zambia for many years to come, especially to replace fossil diesel with biodiesel.

Jatropha ranked highest for biodiesel

Several possible crops can be used for the production of biofuel. For biodiesel these include cotton, Jatropha, rape, sunflowers, soya beans, groundnuts, oil palm, avocado and castor oil seeds. For bioethanol, possible sources include maize, sugar cane, sweet sorghum, cassava, sweet potatoes and switchgrass. The choice of raw materials depends on the climate and the socioeconomic context that prevails in a particular country or region.

In Zambia, various energy crops have been assessed and analysed with regard to the development of biofuel. Twelve criteria have been used in this assessment, including the form of ownership, production, technology, new job opportunities, resistance to external influences, diversity of by-products, minimum size of investments required, the extent of the market, demand for land, demand for water, food supplies, the land's fertility, geographic coverage and impact on the environment.

When it comes to biodiesel, *Jatropha curcas* was the highest ranked, followed by oil palm. Jatropha is resistant to drought and can be grown almost anywhere in the country. Palm oil generates high energy production, but can only be cultivated in certain areas with high precipitation, and is less suitable for small-scale cultivation and refinement. Unlike palm oil, Jatropha oil is not edible and it is therefore much less likely that there will be conflicts with food production.

Jatropha curcas

Jatropha curcas (from the *Euphorbiaceae* family) is a large, coarse bush measuring between 5 and 8 metres. The fruit resemble capsules and are 2.5–4 centimetres in diameter. They are yellow when ripe and turn dark brown after drying. The fruits contain two or three seeds. These seeds contain an average of 35–37 per cent oil, although there are reports of up to 55 per cent oil. Jatropha can be propagated using the seeds, cuttings or seedlings. The cuttings have a lifetime of 10–15 years, while plants from seeds or seedlings have a lifetime of more than 50 years. Jatropha is relatively easy to establish, but like all crops it requires the ground to be prepared. Jatropha grows well in drained soil in warm areas with temperatures ranging from 20 to 32 degrees Celsius. It cannot withstand frost or cold nights, and requires between 300 and 1,500 millimetres of rain a year. It can grow at up to 1,500 metres above sea level. In the event of a prolonged drought, most of the leaves fall off to reduce transpiration. Jatropha is believed to come from Central America and the West Indies. It has been found in Zambia for more than 300 years. It is cultivated in many different ways depending on its purpose, for example as living fencing, as an adornment in private gardens, as support for other crops, and in commercial cultivation for the production of biodiesel.

The Jatropha seeds are approximately 2 centimetres in length – and very rich in oil.

What is produced – and for which market?

Every part of the Jatropha plant, including root, leaves, latex, seeds, bark and twigs are used for everything from medicines to fuel and even environmental control to protect cultivated land from animals. Jatropha is reported to have more than 1,600 applications, primarily due to the fact that the vegetable oil can be converted into the alcohol glycerol, which itself has around 1,500 uses or applications.

Jatropha oil has been used for centuries in lamps, as a source of light that burns without producing smoke. The oil has long been used to make soap in several African countries, and more recently it has been used as a fuel in vehicles and generators. The press cake that is obtained as a by-product from the oil production can be burned or can be converted into charcoal. It is also widely used for the production of biogas for cooking and heating. The Jatropha cake is rich in nitrogen, phosphorus and potassium, and can thus be used as an organic fertiliser, which has proven to be far better than cow dung. Various analyses have shown that the nutritive content of jatropha cake is relatively high compared to inorganic (fossil) fertilisers. This means that rural areas can produce organic fertiliser that is not only easily accessible, but that also contributes to reducing production costs for agriculture, both of which contribute to a more secure food supply.

Biodiesel produced from vegetable oils has proven to be the only option in the short term for replacing fossil diesel, which is dominant over petrol in most regions of the world. Dependence on petroleum products permeates all sectors, not only transport. Pharmaceuticals, chemicals and almost all base industries are dependent on oil products. However, oil extraction seems to be approaching its global peak, and with high prices such as those that occurred during 2007–2008, developing countries such as Zambia are particularly vulnerable as this raises the price of just about all goods and services to unaffordable levels.

There are several different types of oil extraction machines, ranging from very simple presses for family farms to larger, more sophisticated equipment for large-scale operations. Using simple oil pressing methods, the rural population can become involved in the small-scale Jatropha industry. The products can either satisfy the people's own needs or be sold to companies and commercial distributors.

Commercial involvement in the biofuel industry in Zambia has generally been based on a few different working methods, including 1) *self-contained systems* for those who already own land (can be located anywhere in Zambia), and who often choose to use all the by-products themselves rather than selling on the market; 2) *outgrowers*, for small-scale to large-scale farmers who have been contracted to grow Jatropha for a contractor – these farmers are located within a radius that is economical for the parties to the contract; 3) *open systems*, for those who are free to sell to a purchaser on the market – will be spread over the whole country; and 4) *hybrid systems*, comprising combinations of the other systems.

Important plant for the economy of family farming

One interesting aspect when it comes to Jatropha-based industry in a developing country like Zambia is that the farmer is the primary market, i.e. the products from the Jatropha plant are used primarily for self-sufficiency. A family farm with two parents and six children requires certain products and utilities each year, as can be seen from the example in the table. The fertiliser is used to grow maize and vegetables for the family and others who work on the family farm. Electricity is not available in rural areas, and the specified amount relates to what is required to generate electricity for lighting for a few hours in the evenings.

An example that illustrates the value of the Jatropha industry for household economy in Zambia. The table shows what it would cost for a family farm to procure or purchase the same products or utilities using (external) sources other than Jatropha.

Type of utility	Litres	Kilograms	Cost (US dollars per year)
Fuel (diesel per year)	4,224		9,051
Soap (corresponding oil per year)	24		288
Charcoal		4,800	1,097
Fertiliser		1,000	1,143
Mosquito repellent (corresponding oil per year)	3		103
Electricity production	1,095		2,346
Total	5,346	5,800	14,028

The annual cost for supplying these utilities from energy sources other than Jatropha is approximately 14,030 US dollars. By Zambian standards, this is an enormous amount of money, equivalent to many times the typical annual family income. All the utilities in the table can be produced using Jatropha oil and Jatropha cake.

Reducing deforestation and improving agriculture

The use of Jatropha oil and Jatropha cake reduces greenhouse gas emissions from fossil fuels, yet it also entails other benefits for the environment. The use of coal and wood as fuel is increasing at an alarming rate in Zambia. Carbon and biogas from Jatropha cake and electricity generated with the aid of Jatropha oil/biodiesel in generators can reduce deforestation by replacing coal and wood. In addition, the areas that have already been deforested can be made green once more through growing Jatropha, since it is a perennial plant with deep roots that can improve the soil.

The threat of expensive fossil fuels and the consequences of energy shortages could hinder rural development and constitute a serious problem for poor countries such as Zambia. It therefore appears as though Jatropha can have an important role in reducing uncertainty as regards future supply of oil, will contribute to the rural economy and will improve agriculture. Zambia has plenty of land and food production is not threatened by the biofuel industry. On the contrary, when Zambia can utilise energy crops such as Jatropha, the biofuels can protect the land against impoverishment, and at the same time provide a more sustainable energy system and reduce emissions of greenhouse gases.

Issues that need to be taken into consideration in order to promote the development of the Jatropha industry include politics and regulation, sector-wide strategies, land distribution, production costs, trade-related measures, the utilisation of efficiency gains and better public awareness of the economic and environmental value of jatropha.

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Thomson Sinkala is Adjunct Professor at the University of Zambia. He received his Ph.D. from Luleå University of Technology in Sweden, based on an analysis of the social and environmental impacts from mining in Zambia. He is Chair of Zambia's bioenergy association and Managing Director of Thomro Biofuels, which produces biodiesel and other products from Jatropha.

Attractive coasts are vulnerable to climate impacts

Many coastal areas will be affected by climate change. People need to prepare for climate impacts such as sea-level rise, higher and more frequent storm surges, and changes in ecosystems. It is important to consider the effects of today's coastal planning decisions on future generations. Doing nothing will be costly from both a human and financial perspective, write Richard J.T. Klein and Annika E. Nilsson. They use the examples of Bangladesh, the Arctic and the Netherlands to illustrate their case. But the best way of limiting the long-term costs is to slow down climate change by reducing emissions of greenhouse gases. After all, it is hard to imagine how even a rich country could cope with a rise in sea level of several metres.

Richard J.T. Klein, Stockholm Environment Institute.

Annika E. Nilsson, Stockholm Environment Institute.

People have always been attracted to regions where the land meets the sea. River deltas provide fertile land for agriculture, while proximity to water enables fishing and transportation. The services provided by coastal ecosystems support economic development and prosperity, which in turn encourages further migration. Sixteen of the world's 20 biggest cities are located by the sea. In all, one quarter of the world's population lives within 100 kilometres of a coastline and less than 100 metres above sea level, and this fraction is growing fast.

The rapid increase in population in coastal areas puts pressure on both ecosystems and infrastructure. At the same time, people have disrupted many of the natural processes that once created coastlines, for example by cutting down forests and building dams and roads. Coasts built by sediment are especially vulnerable to such disruptions. With climate change comes additional stresses. Rising temperatures cause ocean water to expand and ice in glaciers and at the poles to melt, leading to a rise in sea level. In recent years the pace of the rise has accelerated, and now stands at about 3 millimetres per year. A warmer world also means that storms can gather more energy, particularly in tropical areas, where 120 million people are already exposed to such storms every year. Between 1980 and 2000, tropical storms killed 250,000 people.

How coastlines change as the world grows warmer will depend on the conditions brought about by complex and ongoing interactions between ecosystem dynamics, social change, economics and politics. The three examples below – Bangladesh, the Arctic and the Netherlands – show how climate change is already affecting or will affect coastal societies. The message that links these examples is that populations in seaboard zones will need to adapt to climate change, and that the cost of both the effects of climate change and adapting to it will increase exponentially if further global warming is not prevented.

Bangladesh

In November 2007 cyclone Sidr – one of many cyclones that affect the region – hit the coast of Bangladesh. Like other cyclones, Sidr had gathered energy over the Bay of Bengal and moved in over the low-lying delta. As well as winds of over 260 kilometres per hour and torrential rains, five-metre high waves swept in over fields and villages. In the aftermath, people walked among the wreckage of destroyed homes looking for anything to salvage, while the bodies of the dead were left in the fields. The official death toll is 3,447, but some accounts reported up to 10,000 casualties.

Some local officials have described the damage from Sidr as being even worse than that of the cyclone of

April 1991, considered to be the most damaging of the past twenty years. However, the death toll of the 1991 cyclone was around 140,000, and a weaker cyclone in 1970 killed more than half a million people. Therefore it is initially surprising that when such a strong cyclone struck the most densely populated delta in the world, situated in one of the poorest countries, that the death toll was less than 10,000. What is the explanation for this?

The 1991 cyclone made people realise that super-cyclones are not unique events: sooner or later, Bangladesh would be hit again. At the same time, politicians and the public became more aware of climate change, and Bangladesh was identified as one of the countries most exposed to sea-level rise. During the 1990s the Government of Bangladesh, many international aid organisations and a large number of national and local organisations embarked on a very ambitious programme to increase preparedness for cyclones among the country's coastal population. Cyclone shelters were built (which are sometimes used as schools or community buildings), the Sundarban mangrove area was protected (mangroves provide protection against high waves), and people were trained in how to respond when the alarm was sounded (including evacuation). In addition, responsibility for disaster management was established more clearly at both the national and local level. In previous cyclones a large majority of the victims were women and children, who tended to stay at home while the men fled to higher land. For this reason awareness-raising efforts were aimed specifically at women, and cyclone shelters were built especially for their use.

The effectiveness of such measures can be seen not only when comparing fatalities from Sidr with fatalities from previous cyclones in Bangladesh, but also in comparison with countries that have not implemented similar programmes. In April 2008 cyclone Nargis hit the coast of neighbouring Burma, where cyclone preparedness was minimal. Cyclone Nargis was less powerful than Sidr, yet it killed at least 140,000 people.

The impacts of climate change are most dramatic in connection with tropical storms, but the loss of land on which to live and grow food is also a major issue in highly populated areas such as Bangladesh, and the combined effects of human activity and climate change weaken the ability of ecosystems to provide important services. For example, large-scale conversion of mangrove forests into fishponds poses a major threat to these ecosystems and their biodiversity, with climate change providing an additional stress. Mangrove forests support rich communities of fish and crustaceans, provide energy for coastal food chains, bind carbon in plants and animals and their detritus, and protect coastal areas from storm surges. Ironically, this protection is threatened when it is needed most.

The Arctic

The village of Shismaref, Alaska, is home to about 590 Inupiat (an Inuit people). It is perched on a sandy island on the northwest shore of Seward Peninsula. In 2002 the people of Shismaref voted to move their village to higher ground because the sea is slowly eroding the shore, leaving houses in danger of tipping into the sea or vulnerable to further erosion. The UN's Intergovernmental Panel on Climate Change (IPCC) has identified the Arctic as one of the regions where there is evidence of climate change impacts on coasts. Shismaref is just one of many villages in the North American Arctic facing these impacts. A study has counted that no less than 184 villages in Alaska are at risk for flooding and erosion. Four villages in immediate danger are already planning to relocate, and, as with many issues surrounding the impacts of and adaptation to climate change, it is far from clear who can or will pay the immense economic costs.

A combination of factors lies behind the erosion, illustrating the complexity of coastal processes. Shismaref is situated in a permafrost area, where only the uppermost layer of soil thaws out in the summer, while the soil below remains frozen. In this area the sea is also covered with ice for the majority of the year, which protects the coast from waves. This protection is especially important during autumn storms. However, the Arctic is one of the most rapidly warming regions in the world, with an increase in average winter/spring temperatures of 1 degree Celsius per decade since the 1980s. The direct consequences include thawing permafrost and dwindling sea ice. In 2007 the Arctic sea ice reached a record low, and the years of 2008 and 2009 have also featured very little sea ice.

For indigenous communities in the Arctic, coastal erosion is only one of many problems that a warmer climate will bring. Climate change and shrinking ice will also affect wildlife. Because hunting is often central to Arctic cultures, climate change also presents a threat to cultural and spiritual identity. And it does so at a time when indigenous cultures are facing major social challenges in the form of increasing encounters with a globalised world.

If the future looks bleak, it also holds some possibilities. Relocating a village offers opportunities to plan for future climate change and to build infrastructure that addresses basic needs such as clean water and sanitation. What will or will not happen depends on a range of factors that are relevant to all societies that have to adapt to climate change: What economic resources can a society muster? What is the social and political capacity to make decisions and to implement them? What is the capacity to adjust to new circumstances without disrupting the social networks and cultural identities that people need for their physical and mental well-being?

The Netherlands

The Dutch have a long history of controlling water in an attempt to make the land in the delta of the rivers Rhine, Meuse and Scheldt inhabitable. Today, as a result of centuries of claiming land from the water, more than half of the Netherlands is below sea level, and more than 60 per cent of the 16 million population live in these areas. As a result, an effective system of water control is needed to keep the land dry. The beginnings of such a system originate from around the 10th century when people started building dikes to protect areas from being flooded. In the 13th century, water boards were set up to maintain the integrity of the dikes and waterways, and to control the water levels. They are the oldest democratic institution in the Netherlands, and their function has basically remained unchanged to this day.

However, it has not always been possible to master the water. As recently as 1953, the dikes in the south-western part of the country burst. In the subsequent flooding 1,853 people lost their lives. The Dutch government responded by embarking on an extremely ambitious engineering programme, known as the Delta Works. Its goal was to block a number of large tidal inlets, turning them from marine estuaries into freshwater lakes. Halfway into the programme the plans were changed in response to environmental concerns, which resulted in the construction of two moveable barriers.

Climate change and sea-level rise pose yet another challenge to the Netherlands. Like Bangladesh it is exposed to sea-level rise, but unlike Bangladesh it already has in place an extensive protection system. The population density and economic importance of the area already below sea level leaves the Dutch no other option than to continue to protect the land against the sea, at an ever increasing cost to future generations.

Costly to do nothing

This chapter illustrates the diversity of coastal environments and their vulnerability to climate change. Many other coastal environments are also vulnerable, including small islands in the Pacific and Indian Oceans and the Caribbean. Despite the diversity of these environments, there are a number of common lessons that can be learned.

Firstly, climate change is happening now, and it is making existing vulnerabilities in society apparent. Coastal areas are particularly vulnerable because of a combination of physical factors, such as sea-level rise and erosion, and socio-economic factors that create challenges to adaptation, such as rapidly increasing populations, rapid urbanization, and poverty.

Secondly, it is becoming necessary to adapt. Many adaptation measures will have benefits (that is, save lives and protect land and property) independently of climate change. And adaptation does not need to be large-scale, expensive and predominantly technological, like in the Netherlands. Adaptation also includes capacity building, early warning systems and institutional change, like in Bangladesh.

Thirdly, adaptation will require long-term investment. One-off solutions are not sufficient, as can be seen in the Netherlands, so it is important to consider the future implications of adaptation decisions made now, including the costs to future generations. Doing nothing will be more damaging in the end, both in human and economic terms.

Finally, the best way to limit the costs of adaptation and to ensure that it is effective is by preventing climate change through reduction of greenhouse gas emissions. If the climate continues to change unchecked, then sooner or later the limits to adaptation will be reached. It is hard to imagine how even a rich country like the Netherlands could cope with a sea-level rise of several metres, which would be the case if the Greenland ice cap were to melt.

Doctor Richard J.T. Klein is a geographer focusing on climate adaptation and climate policy. He is a senior researcher at the Stockholm Environment Institute, where he is responsible for co-ordinating the Institute's climate work. He has been involved in several IPCC reports and leads a number of research projects focusing on vulnerability and climate adaptation as a process.

Doctor Annika E. Nilsson is a multi-disciplinary researcher with a background as a science journalist. She works at the Stockholm Environment Institute, carrying out *research on the interplay between science and politics, including in the climate field. Two of the research areas in which she is involved are the relationship between global and local processes as well as climate change in the Arctic.*

Put the climate right
– for the sake of safety

Will climate change give rise to conflicts and war? This issue must be examined scientifically and in detail, writes Peter Haldén. He has studied the future consequences of moderate climate change in Darfur and the Arctic. His conclusion is that the climate does not give rise to conflicts – people do. However, drought and famine can make the situation worse. Oil becoming accessible in the Arctic as the ice melts is a ticking climate bomb. If we fail to mitigate climate change, we will be living in an uncertain world by the end of the century.

Peter Haldén, Swedish Defence Research Agency (FOI).

The climate is changing – the world's most prominent scientists in the field now agree on this fact. They also agree that the change is caused by human influence. The IPCC's most recent report also makes it increasingly clear what effects a changed climate could have for people, animals, vegetation and ecosystems. The issue has received extensive coverage in the media, and has made a breakthrough in public awareness and within politics. On a general level at least, there appears to be consensus that something has to be done. "What" and "how", on the other hand, still appear to be open to debate.

On the scientific side, researchers agree to a great extent when it comes to climate change, and the ecological consequences are now beginning to be generally recognised. However, there is considerable uncertainty regarding the consequences of climate change for society. Very little has been done in this field in terms of studying international policy. Yet there has been no lack of speculation. Both the media and politicians have stated that climate change might give rise to a series of conflicts. At times, these apprehensions have been linked to a future shortage of vital resources, such as water and soil. At times they have been linked to the streams of refugees that, according to some commentators, will arise as a result of drought or because of rising sea levels.

The issue of whether climate change will lead to or contribute to conflicts is important for politicians and the general public. For this reason, any possible links must be examined in detail in a scientific manner. The IPCC has developed scenarios for varying degrees of climate change, depending on how much we do to halt them. In my research, I have focused primarily on possible consequences in a future where we have partially halted climate change, yet still have a warmer climate and problems in the form of droughts, flooding and "wilder" weather, i.e. moderate climate change. The most significant conclusion is that climate does not give rise to conflicts – people do.

Political structures determine the risk of conflict

Some accounts give the impression that an altered climate will automatically lead to conflicts, primarily within, but perhaps also between, states. In order to determine the risk of conflict, however, we have to take a whole series of other circumstances into consideration. Firstly, climate change is "filtered" in international politics through pre-existing conditions. In a region that is characterised by poverty, undemocratic regimes that consolidate their power with violence, and whose nations are very prone to entering into conflict, climate change can entail increased risks. Regions with stable economies, responsible and capable governments and peaceful international relations, on the other hand, have the potential to handle the challenges in the spirit of co-operation. Climate change may also be used by unscrupulous leaders who want to strengthen their position of power through violence. In this case, too, the risk of conflict is not solely dependent on the climate, but also on political structures and decisions.

Two areas are often highlighted as ongoing or potential areas for climate conflicts – Darfur and the Arctic. In both cases, the decision whether conflict will arise lies in the hands of politicians, not in the forces of weather.

Civil war in Darfur – drought makes life more difficult

According to a number of commentators, the conflicts in the Darfur region in Sudan are due to a prolonged drought that has resulted in the cattle-herding nomadic people starting to fight with resident farmers for the increasingly scarce fertile ground. Even though this explanation may sound logical, it is insufficient. The conflict in Darfur must be viewed in the wider context of a civil war between Sudan's government and various groups that are striving to achieve independence. Ever since the 1980s, the government has ruled unsettled areas by setting various militia groups against each other and by waging war against the civilian population in areas that might possibly support the rebels. The underlying reasons for the conflict are consequently not related to the climate, but to the civil war. Nevertheless, the drought makes life much more difficult for the hundreds of thousands of refugees, and threatens these already vulnerable people.

Many have expressed apprehensions about the fact that poorer access to natural resources such as agricultural land, water and ecosystems might lead to conflicts. However, research has shown that it is difficult to link environmental disasters of this type to armed conflicts. On the other hand, it is absolutely clear that people's health, living conditions and their potential for development are drastically impaired. The United Nations Development Programme (UNDP) has coined the expression "human security" to clarify the distinction from the traditional understanding of security that is associated with armed threats against nations and communities. Human security is a much broader concept as it is related to welfare and development, and the threats are not only armed conflict, but also environmental destruction, famine, natural disasters and the absence of development. It is above all security in this sense that is threatened by both major and minor changes to the climate.

Sea routes opening in the Arctic

Global warming is causing the Arctic ice caps to melt, at sea and on land. According to the latest calculations, the sea ice will have retreated to such an extent within ten years that the previously frozen ocean will be navigable. This major change means, in theory at least, that a large proportion of the freight that is transported between Europe and Asia and between Europe and the USA's west coast could be rerouted. The route between Hamburg and Yokohama would then be halved and large savings would be made. There has been speculation as to whether the new shipping routes could lead to conflicts between the superpowers. Although this may sound both reasonable and daunting, there are two important aspects that are seldom mentioned in the debate.

Firstly, since the 1980s, there has been an international framework of legislation regulating international shipping, in particular how much territory at sea an individual state has under its jurisdiction and how much is shared. Most countries in the world have signed the United Nations Convention on the Law of the Sea (UNCLOS). The USA has not done so, but recently declared that when it comes to the Arctic Ocean, it will respect the Convention's rules which state that a country's territorial waters extend 200 nautical miles from its coast. The waters beyond this limit are international waters. Under the UNCLOS, however, commercial vessels are entitled to pass through a country's territorial waters. This means that there are no legal barriers to traffic in the Arctic.

Secondly, it is in the economic interests of all nations, in particular Russia's, to keep shipping routes open. Consequently, it is difficult to imagine serious conflicts regarding the issue of whether they should be kept open or closed. The risk of conflicts between countries due to the altered climate in the Arctic is not that great, although increased human activity in the form of shipping and the extraction of natural resources will cause considerable stress to what is at present a relatively untouched environment.

The Arctic's natural resources are becoming accessible

Perhaps a greater issue in the Arctic relates to the considerable natural resources available and who is entitled to extract them. There are large deposits of oil, gas and minerals both on land and at sea in the Arctic, and these will be possible to extract in the future when the ice melts and technology improves. This can be viewed from three different perspectives: energy security, traditional military security and climate security. From an energy security perspective, access to oil can be safeguarded when sources in other parts of the world run dry.

From a traditional military perspective, apprehensions have been expressed regarding the fact that the now accessible deposits could cause tensions between the countries that border the Arctic Ocean: Denmark, Canada, Norway, Russia and the USA. Even though this may appear probable at first glance, there is much to argue against it. To start with, there is an international framework of regulations that determines who is entitled to which assets on the sea bed, as well as provides clear rules regarding how to determine any disputes in international courts.

Secondly, the economies of the Arctic nations are intertwined. Even if situations were to arise where a consumer's dependence on an important resource could be utilised, all the parties involved in the Arctic would lose from a situation whereby everyone is endeavouring to keep the oil for themselves rather than to trade in it. In addition, many of the countries and companies are dependent on co-operation with each other for technology and knowledge, making a future where nation stands against nation in the Arctic less likely. The leaderships in the countries bordering the Arctic have also realised this, and recently entered into an inter-state treaty, the Ilulissat

Declaration, in which they all undertake to handle the issue of the Arctic's future jointly and in collaboration.

Arctic oil a ticking climate bomb

From a climate security perspective, the oil and gas in the Arctic represent a major problem, as it will become much more difficult to achieve the goal of reducing climate change if we start extracting the oil there. A major challenge in the future will consequently be to try to compromise and achieve a balance between these three security perspectives: energy security, military security and climate security. This may be difficult, because the potential to extract large volumes of oil from the Arctic Ocean offers a tempting short-term solution to the rising demand for energy, although at the same time entails a ticking climate bomb.

In this context, it is important not to forget the six million people who live in the Arctic: Inuits, native Americans and Siberian indigenous peoples. For them, melting sea ice and a changed climate will have dramatic consequences. The traditional ways of life and culture are built up around interaction with the polar landscape. When the landscape changes on a fundamental level, the way of life also has to change. For them, climate change is a security issue, although not a military one, and there is nothing they can defend themselves against, either.

Large-scale conflicts unlikely

If moderate climate change will not necessarily lead to conflict, but might even result in collaboration, what about large-scale climate change? This question is difficult to answer, as we have no previous experience to go on and the more extreme changes are a long way in the future. Despite these reservations, we can state that if we do not do anything about climate change, the Earth will experience major changes within a century. If things turn out as in the IPCC's worst-case scenarios, with sea level rises of a metre or more and a world that is 6 degrees warmer, communities and nations will be subjected to enormous stress. In these scenarios, food supplies will be rendered more difficult in many places and there will be a very dramatic decline in the world economy. Such a future is not a stable world, but could entail major challenges to peace and security.

However, it is important to point out that even major natural disasters and famine will not necessarily entail armed conflicts. Often, such major stress means that the resources for large-scale conflicts are reduced in the same way as the resources for looking after and managing society are reduced. The consequences can be a great deal of human suffering and a large number of small conflicts, some of them armed, although large-scale wars are unlikely. In other words, if nothing is done to reduce climate change, we will be facing an uncertain world towards the end of this century. However, if we reduce emissions of greenhouse gases, we may very well succeed in avoiding increased conflicts due to climate change. In other words, we are at an important crossroads.

Peter Haldén holds a PhD in Political Science. He has worked at the Swedish Defence Research Agency (FOI), focusing on climate change, the environment and security, as well as on security policy in Africa. He is currently working on a postdoctoral project at the University of Helsinki regarding constitutions and international security.

Recommended reading

- Peter Haldén. *The Geopolitics of Climate Change*, FOI 2007 (www2.foi.se/rapp/foir2377.pdf).

MITIGATION OF CLIMATE CHANGE

Climate measures in an uncertain world

When we try to set emissions targets for carbon dioxide, we have to put up with many uncertainties. It is not certain how much the temperature will increase by when the concentration of greenhouse gases in the atmosphere increases, and it is not certain what effects a global increase in temperature will have, writes Daniel Johansson. Neither is it obvious what should be classed as "dangerous anthropogenic inference with the climate system". If we want to be relatively sure of reaching the EU two-degree target, we have to start reducing emissions drastically right now and continue for the next few decades. There will then be more room for manoeuvre later on.

Daniel J.A. Johansson, Department of Energy and Environment, Chalmers University of Technology, and Department of Economics, University of Gothenburg.

The fact that the climate is changing is a reality. The fact that this is primarily due to anthropogenic interference can also be stated with almost as much certainty. The activities that contribute most are society's use of fossil fuels, global deforestation and the world's food production. These activities have resulted in a dramatic increase in the concentration of the greenhouse gases carbon dioxide, methane and nitrous oxide in the atmosphere. As a consequence of this, the balance between incoming solar radiation and outgoing thermal radiation has been altered, which in turn is leading to the temperature on Earth increasing. This unnaturally high temperature level will last for thousands of years into the future. If we want to prevent excessively large temperature changes, how much should we reduce our greenhouse gas emissions by, and in what way?

With the signing of the UN Climate Convention in 1992, it was clear that decision-makers the world over could not accept a significant human impact on the Earth's climate. A central aspect of the Convention is that the concentrations of greenhouse gases in the atmosphere must be stabilised at a level to "*prevent dangerous anthropogenic interference with the climate system*". The UN Climate Convention is a starting point for discussing the amount by which emissions of greenhouse gases should be reduced and the extent of changes in the climate that are acceptable. However, it is not easy to translate the content of this Convention into tangible goals in relation to global average temperature, concentrations and emissions of greenhouse gases.

When does man's impact on the climate become "dangerous"?

It is often said that global emissions of greenhouse gases have to start to fall before 2015 if we are to be in time to prevent dangerous climate change. Such statements give the appearance of complete and entirely objective knowledge and evaluations of what is dangerous, but this is far from the truth. We cannot rule out the possibility that the current concentration of greenhouse gases is already too high to avoid dangerous climate change, that we should have started reducing global emissions perhaps ten or even twenty years ago. However, neither can we rule out the possibility that emissions can continue to increase for a number of decades without it being too late to halt dangerous climate change. It all depends on what we mean by dangerous climate change, how sensitive the climate is to increased concentrations of greenhouse gases in the atmosphere, and what effects an increased temperature will have on ecosystems and society.

To start with, an interpretation of dangerous climate change is subjective and value laden. Many will agree that the melting of Greenland's ice sheet with a resulting rise in sea levels of 6 metres or the drying out of the Amazon rainforest is dangerous human impact. It is more difficult to draw the line for what is dangerous when it comes to geographically dispersed changes such as changes in precipitation or the melting of smaller glaciers. These geographically dispersed changes can take place abruptly and appear serious for those involved, although perhaps not for those who are not directly affected. The interpretation of what is dangerous depends, in addition to fundamental values, on factors such as what potential we have to adapt to changes in the climate, which in turn is dependent of our level of income, for instance. Poor people will be affected most by climate change.

Two extremely uncertain factors

Secondly, the links between global average temperature change and various effects are uncertain and very complex. Despite this, we know for certain that the likelihood of dangerous climate effects increases the more greenhouse gases are emitted. The link between danger and global average temperature must consequently be interpreted from a risk perspective.

Thirdly, there is also considerable uncertainty regarding how the global average surface temperature alters as a result of changes in the concentration of greenhouse gases in the atmosphere. The UN's climate panel, the IPCC, wrote in its most recent report that when warming has stabilised after a doubling of the concentration of carbon dioxide in the atmosphere, the global average surface temperature will probably increase by between 2 and 4.5 degrees. This measure is generally referred to as climate sensitivity, and should not be confused with the IPCC's scenarios for temperature changes by 2100. Note however that climate sensitivity can be both higher and lower than that specified in the IPCC's range.

In summary, two very uncertain aspects must be taken into consideration when determining emissions goals, both the uncertain effects of a change in the global average surface temperature and an uncertain level as regards climate sensitivity. In addition, it is also necessary to interpret what is to be deemed dangerous.

Climate sensitivity – a definition

Climate sensitivity refers to the long-term, stable increase in global average surface temperature that takes place as a consequence of a doubling of the carbon dioxide concentration in the atmosphere compared to the pre-industrial level.

The EU two-degree target as a starting point

The EU has adopted a goal of a maximum global average temperature increase of 2 degrees above the pre-industrial level. This is consequently the EU's interpretation of what global average temperature change we can accept in order, with a sufficient level of probability, to avoid a dangerous impact on the climate system.

This is also the level of temperature change that a series of other countries have adopted as their goal and that several climate scientists have suggested as an upper limit. However, we cannot rule out the possibility that, in hindsight, this will be viewed as an overly weak or, on the other hand, an overly stringent target. Such a temperature target nevertheless provides a starting point for discussing necessary emissions reductions, both now and in coming decades.

Climate sensitivity decisive

I wrote previously that climate sensitivity is very uncertain. Its significance for necessary reductions of carbon dioxide emissions from the global energy system in order to achieve the EU two-degree target is illustrated in figure 1. This figure has been produced based on results from the MiMiC model, which has been developed at the Division of Physical Resource Theory at Chalmers University of Technology. The model looks for solutions for reducing emissions of

Emissions scenarios compatible with the EU two-degree target

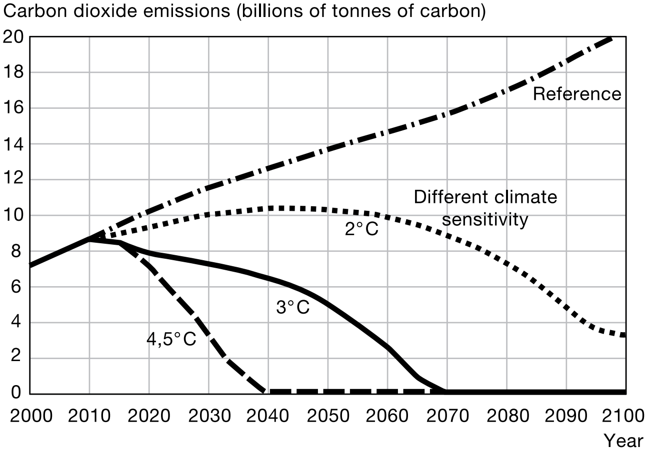

Figure 1 shows emissions scenarios for carbon dioxide from energy systems that are compatible with the EU two-degree target. The emissions profiles are calculated using different assumptions about the climate's sensitivity to changes in the atmospheric concentration of greenhouse gases. 2 degrees, 3 degrees and 4.5 degrees indicate the mean surface temperature increase in equilibrium of a doubling of the carbon dioxide concentration in the atmosphere, i.e. the value of climate sensitivity. The reference scenario indicates what emissions can be expected to be if nothing is done to reduce society's climate impact.

carbon dioxide, methane and nitrous oxide at the lowest possible cost in order to achieve a given goal for global average temperature. It takes into consideration factors such as climate sensitivity, the thermal inertia of the climate system, the lifetime of the gases in the atmosphere and estimated costs for reducing global emissions.

Figure 1 clearly shows that different climate sensitivity values stipulate fundamentally different requirements in the form of emissions reductions from the global energy system in order to achieve the two degree target. If climate sensitivity is high (4.5 degrees), emissions must decrease drastically over the coming decades and thereafter, whereas if climate sensitivity is low (2 degrees) the problem is not nearly as acute.

If we want to be relatively sure of achieving the two-degree target, we have to start following a stabilisation scenario that is in line with those in figure 1 where the climate sensitivity is medium (3 degrees) or high (4.5 degrees). As well as being on the safe side, significant measures today and in future decades will provide a greater possibility at a later date to determine desirable concentration levels for greenhouse gases in the light of new and better knowledge. If we emit large amounts of greenhouse gases today and in future decades, the potential to stabilise the concentration of greenhouse gases at a low level will be reduced. We will then have both created higher levels of greenhouse gases in the atmosphere and expanded the capital stock of technology that generates emissions.

Minimum of a halving by 2050

Let us assume that we are going to try to achieve the two-degree target with a relatively high degree of certainty. In this case, emissions should be reduced in line with the two lowest emissions scenarios in figure 1. These scenarios show a significant difference as regards emissions compared to the reference scenario. For example, they require a halving or a larger reduction in global carbon dioxide emissions from the energy system by 2050 compared to today. How can we reduce emissions of carbon dioxide from the energy system by so much? It would be naïve to claim that this is simple, but I believe that it is achievable, bearing in mind the technical developments that humanity has achieved in recent centuries and because it is scientifically possible to supply renewable energy in sufficient volumes.

Of course, it is impossible for me or anyone else to say with certainty what technical or political solutions will be available decades or even centuries in the future. What we can do here is to discuss some principles that may form the basis for significant emissions reductions. I will focus on important and currently known measures for reducing carbon dioxide emissions from the energy and transport sectors, but not discuss the great significance of reducing emissions of methane and nitrous oxide as well as carbon dioxide emissions from land usage.

Three ways of reducing energy consumption

The world's primary energy supply is currently heavily dominated by the fossil fuels, i.e. coal, oil and natural gas (figure 2). The potential for reducing carbon dioxide emissions from the energy sector can be roughly divided into three categories: 1) reduce energy consumption, 2) change fuels, and 3) capture and store the carbon dioxide.

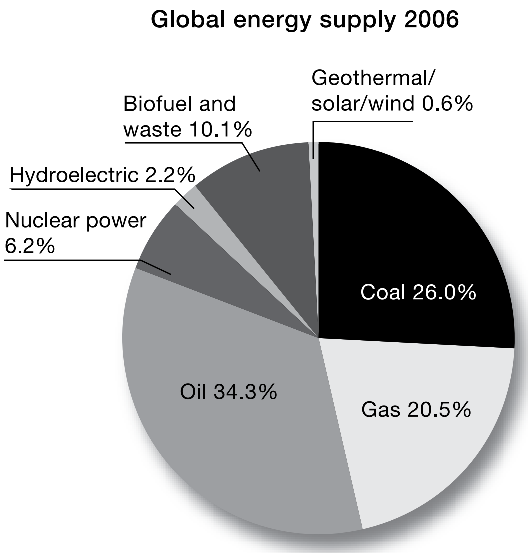

Figure 2. This diagram shows what proportion of the global primary energy supply in 2006 was made up of different energy types. The total global energy supply was approximately 137,000 terawatt hours (TWh).

Reduced energy use can be achieved by making technologies more energy efficient. Examples include passive houses, low-energy light bulbs and hybrid cars. There is enormous potential as regards the use of more energy-efficient technologies. However, reduced energy use does not solely need to be a result of technical solutions, but can also come about as a result of lifestyle changes, such as people deciding against increased material consumption in favour of more leisure time. Of course, this is not yet an option for the vast majority of the world's population, but it may be significant in rich parts of the world, such as in parts of the EU and in the USA.

Changing supply to energy sources that produce less or no carbon dioxide emissions is perhaps the first thing that springs to mind when it comes to reducing carbon dioxide emissions from the energy sector. We can achieve emissions reductions either by switching between different fossil fuels (natural gas releases the least carbon dioxide per unit of energy, while coal releases the most) or by switching from fossil fuels to renewable alternatives (solar and wind, as well as biomass) or nuclear power.

Solar and wind energy growing rapidly

The theoretical potential for solar energy is enormous. Solar insolation to the Earth's surface is approximately seven thousand times greater than society's current energy supply. Unfortunately, solar energy technology is still relatively expensive, and without subsidies it is only profitable in a few places. However, usage will increase with financial support, and with increased usage prices should fall. The costs for wind energy technologies are lower than for solar energy technologies, and in many places this is now the cheapest way of producing electricity. Wind energy can play a significant role when it comes to reducing carbon dioxide emissions as early as the next few decades, while solar energy can be expected to play a very large role further in the future. Although the energy supply from wind and solar sources is fairly small at present, both are growing very rapidly.

Bioenergy (wood, agricultural residue, etc.) are expected to play an important yet limited role. Bioenergy can play a significant role because in many ways they resemble fossil fuels and because, if they are used in a cost-effective manner, they are a relatively cheap way of reducing carbon dioxide emissions. This means that bioenergy can play a fairly major role in the near future. However, their role will be limited, as biomass for energy purposes will probably be in short supply. The residual flows from agriculture and forestry cannot replace more than around a third of today's global oil consumption, and the area of fertile land suitable for energy crops is limited. This in turn means that there is a significant risk of competition for land between bioenergy plantations, food production and the preservation of untouched ecosystems.

A better world without large-scale nuclear power

Finally, nuclear power. In principle this is greenhouse gas-neutral energy source, although it is associated with a number of other problems that cause me to hope that it will not play a decisive role in reducing the world's carbon dioxide emissions. The most important reason is that I simply believe that the world will be a better place without a large-scale expansion of nuclear power.

One of the most serious problems with nuclear power is that, in technical terms, it is not a big step from the production of fuel to the production of nuclear weapons. The fuel production aspect is surrounded by global political disputes. An example of this is the current political manoeuvring regarding Iran, and similar situations are unlikely to become less common if nuclear power expands significantly above the current level. In addition, the more reactors there are, the greater problems there will be with the handling of waste and the increased likelihood of an accident.

Carbon dioxide storage – technology with an upper limit

One technology that I am convinced will be of decisive importance as regards the potential to reduce carbon dioxide emissions drastically in a few decades is the capture and storage of carbon dioxide from stationary, large-scale emissions sources such as power stations, steelworks and heating plants. The safest way of storing the carbon dioxide is probably underground in sealed reservoirs in order to prevent it escaping into the atmosphere.

The great advantages of this technology are that it is expected to be relatively cheap and that it means that parts of the energy system do not need to be altered radically. In principle, we can use power stations that are similar to those we are using at present, although with a number of modifications. In a world of powerful lobby groups (such as the coal power industry), a gradual change from the current situation may be politically easier than a radical change. The main problem with the technology is that there is a small risk of the carbon dioxide slowly leaking out from the reservoirs, which could be a major problem even if the annual leakage is relatively small.

Achieving change

In order to achieve the changes I have described, global political co-operation is required. Discussions are currently under way regarding how to proceed in order to reduce emissions of greenhouse gases once the period of the Kyoto Protocol expires in 2012. It is not unreasonable to think that the industrialised countries should go in advance of the developing countries when it comes to reducing emissions, taking on (at least a significant proportion of) the costs for developing and distributing new technologies, and compensating the developing countries for the damage that climate change will cause. However, developing countries with rapidly growing economies should take responsibility as soon as possible by starting to use technologies that lead to low greenhouse gas emissions. It takes time to change an energy system and its associated infrastructure, so investments in technologies and infrastructure undertaken now and over the next few years will be of great importance for many decades to come.

Reducing emissions as drastically as I have described will not be easy. However, I am convinced that, one day, it will be possible to use only technologies that produce just a small amount of greenhouse gas emissions in order to meet the world's energy demand. What is needed in order to speed up this process is global political co-operation, powerful economic controls and a public desire to achieve this goal.

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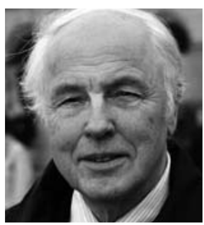
Easier to meet the two-degree target in an electric society

According to studies carried out within the Royal Swedish Academy of Sciences' energy committee, it is estimated that carbon dioxide emissions from fossil energy sources could be reduced from the current figure of 28 billion tonnes per year to 20 billion tonnes by 2050, writes Sven Kullander. According to calculations from the IPCC's scenarios, this ought to be sufficient to meet the EU two-degree target. The goal of allowing the Earth's average temperature to increase by a maximum of two degrees will be possible to achieve by a clear margin as regards carbon dioxide emissions if we switch to an electric society. However, the world's leaders obviously have to agree, and deforestation has to cease.



Sven Kullander, Royal Swedish Academy of Sciences.

The world ought never to have been facing such major changes. At present, 81 per cent of the energy supply comes from coal, oil and fossil gas, and this has to be changed drastically within the next 50–100 years if we are to avoid the climate changes described in the IPCC's various scenarios.

The world's annual energy supply has doubled since 1970, and in 2006 it stood at nearly 140,000 terawatt hours (TWh) per year. At the same time, the world's energy consumption is increasing every year. In the rich countries, attempts are being made to reduce this by using energy more efficiently. Energy consumption is expected to increase in poorer countries, although from a very low starting point. In Europe we use six times more energy per inhabitant compared to Africa and Asia, and three times as much as in Latin America.

During 2006, the world emitted 28 billion tonnes of carbon dioxide from fossil fuels; this entailed an increase of 80 per cent compared to 1973. The starting point for the EU's and Sweden's climate policy is that the Earth's average temperature should not be allowed to increase by more than two degrees. In order to translate this temperature increase into emissions, model calculations must be utilised that have been drawn up within the framework of the IPCC.

A couple of energy terms

Energy supply refers to the amount of energy (primary energy), which includes the fuel's entire energy content, i.e. including the energy that is lost in the form of heat during electricity production in fossil power stations and nuclear power stations that do not employ heat recovery.

The amount of *consumed energy* is the final amount of energy that causes our lights to come on, our engines to work, our rooms to be warm, etc.

IEA's forecast is directly contrary to the goals

In its World Energy Outlook from 2008, the International Energy Agency (IEA) has created scenarios regarding the energy situation in the world up until 2030. In a reference scenario (figure 1), the estimates are based on prevailing policy, while an alternative policy scenario (figure 2) assumes that current production and consumption patterns will change. In the latter, more restrictive case, it is still estimated that the energy supply will increase to 183,500 terawatt hours per year by 2030. However, the proportion of fossil energy is expected to decrease from 81 to 76 per cent. The IEA's scenarios are based on a comprehensive gathering of data, and they ought above all to be realistic with regard to demand for energy. However, the IEA is probably underestimating the strong political desire to reduce carbon dioxide emissions, particularly following the election of the new President in the USA.

Global energy supply 1980–2030
according to the IEA

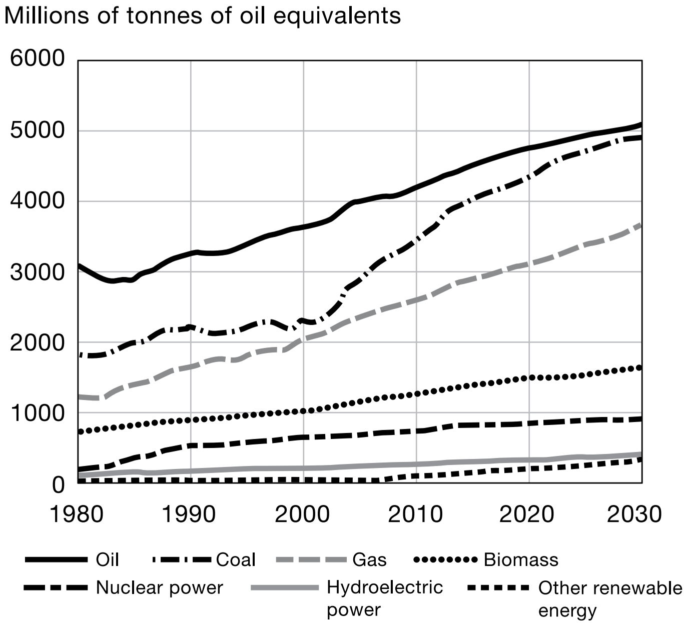


Figure 1. According to the World Energy Outlook 2008 (published by the International Energy Agency, IEA), it is estimated that the annual global energy supply will increase from 136,500 TWh to 206,100 TWh between 2006 and 2030, i.e. an increase of 45 per cent or 1.6 per cent per year. It is assumed that the fossil fuels will increase most. This reference scenario is based on the current policies conducted by the participating countries in the IEA. (1 000 million tonnes of oil equivalents = 11,630 TWh)

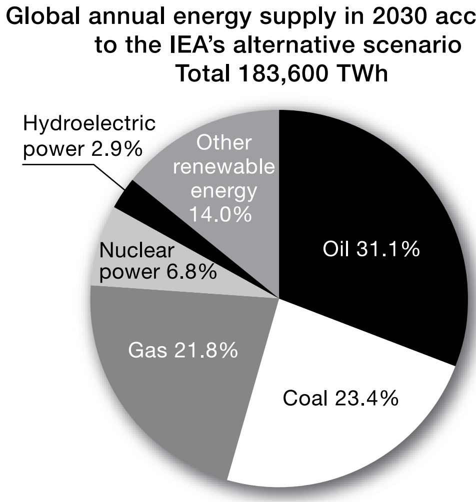


Figure 2. An alternative scenario from the IEA estimates the primary energy supply in 2030 on the basis both of the prevailing policy and of policy that is being considered but has not yet been adopted. Note that, compared to figure 1, bioenergy is also included among other renewable energy.

According to the IEA's alternative scenario, the share of the energy supply made up of renewable energy is calculated to increase from 12.3 to 16.9 per cent during the period 2006–2030. In OECD countries where hydroelectric power in general has been developed, supplemental energy is expected to be provided from wind power and biomass. In other countries, particularly in Asia, Central and South America, the majority is expected to come from hydroelectric power. Nuclear power's proportion of the energy supply is expected to increase from 6.2 to 6.8 per cent per year; a third is electrical energy and the rest is waste heat.

According to the IEA's forecasts, carbon dioxide emissions from fossil fuels will increase from 28 to 34 million tonnes per year between 2006 and 2030. After 2030, the largest emissions will come from coal-fired power stations, as their contribution to the energy supply is increasing. By way of comparison, according to the IPCC, emissions need to be limited to 2,200 billion tonnes over the next hundred years (22 billion tonnes per year on average) in order to stabilise the carbon dioxide concentration at 450 ppm, which gives a 50 per cent likelihood of the two-degree target being achieved. (The IPCC's figures also include deforestation, which currently contributes 25 per cent of carbon dioxide emissions.) The IEA's forecast is directly contrary to the wishes of the politicians. For example, the EU's goal is to reduce carbon dioxide emissions by 20 per cent by 2020.

Alternatives for 2030

However, there are also other ways of looking at future energy supplies than that reflected in the IEA's forecasts. The Royal Swedish Academy of Sciences in Sweden works on energy issues through its energy committee. Its sights are set on a global perspective with a time horizon of around 2050. The Swedish situation is the subject of a special analysis. All of the Academy's subject areas are represented in the work, with an independent evaluation of the current state of knowledge: mathematics, astronomy and space science, physics, chemistry, geoscience, biology, medicine, technology, economics, history of ideas and environmental science. The Academy's extensive national and international networks are an important resource for the work. The deliberations within this article are based in large part on the work of the energy committee.

Bioenergy, hydroelectric power, wind power and nuclear power appear to be the energy types that could contribute substantially to the energy supply in a couple of decades. An increase in electrical energy's share of the energy supply is of particular interest, as the energy types mentioned primarily produce carbon dioxide-free electricity. Electricity is currently largely produced from coal (figure 3).

Bioenergy

It is assumed that bioenergy will continue to increase, primarily through improved cultivation methods, genetic modification and more effective fertilisation. A number of ecological aspects have to be taken into consideration, however, including the preservation of

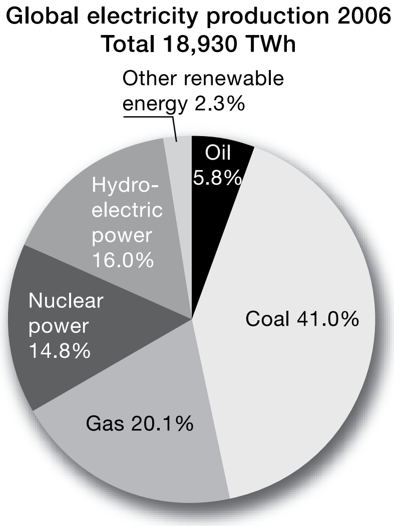


Figure 3. Global electricity production in 2006 according to the IEA's World Energy Outlook 2008. Other renewable energy includes electricity from biomass, solar, wind and geothermally generated electricity.

biodiversity, an acceptable climate function, reduced deforestation and less high-intensity and more ecologically adapted forestry and agriculture. Estimates of future bioenergy potential vary wildly. It is clear that bioenergy will become increasingly important, although the production of food, paper, sawn timber and raw materials for the petrochemical industry will compete for the raw material. In addition, measures must be implemented to reduce existing levels of deforestation, which are currently leading every year to a reduction in the living forests' absorption and binding of carbon dioxide to an extent equivalent to the whole of the USA's carbon dioxide emissions.

The current global population of 6.7 billion people need food at an energy value of 7,100 terawatt hours per year, which can just about be satisfied by today's agriculture. In addition to the energy in the food on our table, input energy is required, primarily fossil energy, that is 5–10 times greater than the energy content in the food. Primary agricultural products should not be used for energy purposes as they are required to satisfy the need for food for the growing population of our planet. When it comes to bioenergy, the focus should instead be on residual products from forestry and agriculture.

There is currently considerable interest in second generation fuels, which are obtained by breaking down cellulose to make sugar or by the gasification of biomass. It is estimated that these fuels could be introduced on a large scale within the next decade. The energy committee judges that the global bio-energy supply could be doubled by 2030, primarily through the use of residue from agriculture and forestry. In the longer term this could be increased by a further 20 per cent through more efficient cultivation methods.

Hydroelectric and wind power

Traditional hydroelectric power is a clean and sustainable energy source that has the major advantage that it can be regulated quickly according to needs. The largest hydroelectric power producers are China, Canada, Brazil and the USA. In total, 3,000 terawatt hours of hydroelectric electricity are produced every year in the world, whereas the estimated technical potential is 9,000 terawatt hours per year. In other words, two-thirds of the potential are not utilised, primarily outside of Europe. Various environmental considerations must be taken into account when developing hydroelectric power. This has been shown in particular by the major Three Gorges dam project in China.

Wind power is now being developed in many parts of the world, and this energy type produces 260 terawatt hours per year globally. One inconvenience is that fossil electricity often has to be used at times when the wind is not blowing sufficiently strongly. The Germans use coal power, the Spaniards gas turbines, while the Danes are able to some extent to utilise Nordic hydroelectric power for regulation. Wind power stations generate electricity for between 2,000 and 3,000 hours per year. If the purpose is to guarantee a stable electricity supply, two to three times more electricity is required from another energy source. Of course, the availability of wind power may be improved to some extent through offshore wind power stations and by developing power line networks over large distances to compensate in part for fluctuations in the wind.

Nuclear power

Nuclear energy is responsible for 14.8 per cent of the world's electricity supply, i.e. 2,800 terawatt hours per year. Most of the 439 reactors currently in service were built during the period 1970 to 1990. The EU's 150 reactors contribute 33 per cent of the Union's electricity supply. Major development programmes are planned in China, India, Russia and the USA. China has plans to order a hundred modern reactors from the American manufacturer Westinghouse, and aims for them to be either commissioned or under construction by around 2020. New reactors are also being discussed within the EU. However, it will take time for the nuclear power industry to get started again after the last twenty years of relative stagnation. In order for nuclear power to be accepted by the general public, however, the problems associated with waste have to be satisfactorily resolved. Sweden is at the forefront in this area. If the political will exists, it ought to be possible to build a couple of hundred powerful new reactors by 2030.

A large proportion of these reactors will be third generation reactors, which have been improved in terms of both performance and safety compared to today's reactors. Fourth generation reactors are also potentially of interest, and these will probably have been fully developed towards the end of the period and be built in the slightly longer term. Fuel consumption will be greatly reduced, the long-lived waste will be destroyed, and various areas of application are planned in addition to electricity production, such as the production of hydrogen and process heat as well as the desalination of seawater. Fourth generation reactors are high-temperature reactors that can use both natural uranium and thorium, with significantly smaller volumes of waste.

The period 2030 to 2050

Demand for energy will probably increase further up until 2050, bearing in mind the considerable demands that must be satisfied for a growing number of people. Two different areas are expected to make a significant impact during this period: rationalisation and solar energy.

Rationalisation will gradually influence energy consumption, although this relates to inert systems. It takes time to regenerate and improve the housing stock and machinery within industry, as well as to replace existing cars with vehicles that run on alternative fuels. Thanks to its high quality (capacity to generate work), electricity is the strongest rationalisation factor within energy usage. Use in the transport sector is of particular interest. Electricity offers a very high level of efficiency here compared to petrol, for which around 25 per cent of the energy content is used for propulsion while 75 per cent becomes residual heat. The introduction of electric cars will therefore entail a substantial rationalisation, as basically all electrical energy is used for the propulsion of the car with only small losses. Today's oil usage within the transport sector (25,000 terawatt hours in internal combustion engines) could theoretically be replaced with 6,000 terawatt hours of electricity for electric motors.

Solar energy

Most forecasts assume that solar energy will become an increasingly important component in the direct energy supply in the long term. The use of solar collectors and solar panels is expanding rapidly. One very promising development that is currently taking place is the improvement in efficiency as regards the conversion of solar energy into solar electricity in solar panels comprising multiple layers of semiconductors. Efficiency levels of 40 per cent have recently been achieved, compared to the 10 per cent which is typical of today's commercial solar panels. Like wind power, however, these systems are dependent on regulating power during periods when the sun is not shining on the panels.

This drawback has been eliminated in another promising technology, known as CSP (Concentrating Solar Power). This is based on concentrating the solar insolation with the aid of mirrors set out over a large area. The solar radiation is concentrated either on a tank situated on a central tower, or on tubes in which liquid is heated to several hundred degrees. The heated liquid can be routed to a large container tank, where it is stored for up to 24 hours. In this way, daily variations are eliminated. The hot liquid can be extracted continuously to convert water into steam, which then drives turbines to generate electricity. This means that electricity can also be produced at night when the sun is not shining. This technology eliminates one of the inconveniences of the renewable energy sources. Experience has already been gained from Spain and the USA, and CSP solar power plants with a combined output of 9 gigawatts (GW) are currently being developed.

The technology has consequently been tried and tested, and several major projects are under discussion. In Spain there are plans to produce more than

60 gigawatts by 2030. Another major project is the Desertec project, which is targeting a large-scale development of the CSP technology in the Sahara and the Middle East, with plans for an extensive transfer of electricity to Europe. In theory, all the world's electricity could be generated in less than one per cent of the world's desert areas.

The extent to which solar electricity will be developed by 2050 depends on political decisions, for example decisions regarding the development of large-scale power line networks. When it comes to small-scale solar electricity systems based on semiconductor technology, the rate of development depends on the development of matching power.

The situation in around 2050

Let us assume that hydroelectric and wind power have largely been developed to their full technical potential, that solar electricity production has succeeded in becoming an important component in the electricity supply, that a further 400 reactors have been built after 2030 and that the expansion of bioenergy has continued after 2030. This results in the scenarios for annual energy supply and electricity supply in 2050 as shown in figures 4 and 5.

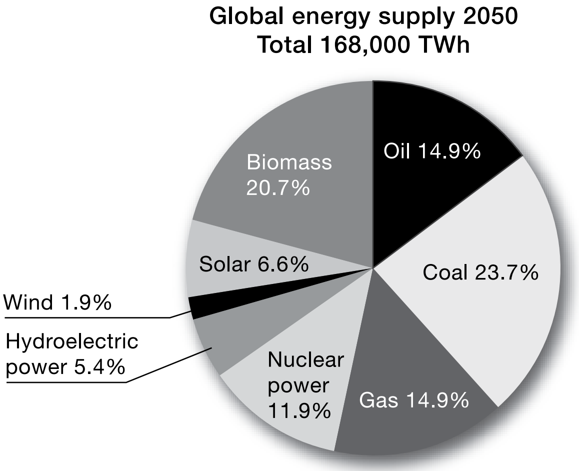


Figure 4. Estimates of the global energy supply in 2050. These estimates are based on information from Uppsala University's group for Global energy systems with regard to fossil fuels, and on the studies that have been conducted within the Royal Swedish Academy of Sciences' energy committee with regard to non-fossil energy sources.

When it comes to the fossil energy types, it is assumed that the oil supply will have halved by 2050 compared to today, that the gas supply will be back at today's level following a few decades of boom, and that coal power will not have been developed by more than is necessary, principally as matching power to renewable energy. All in all, 90,000 terawatt hours of fossil energy will then be supplied, compared to 110,000 terawatt hours in 2006.

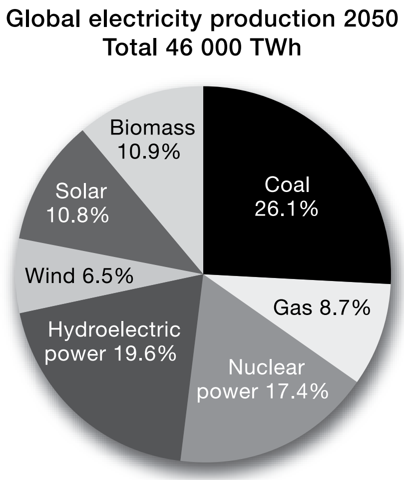


Figure 5. Estimates of global electricity production in 2050. (Same underlying data as for figure 4.)

It is fully realistic to assume that a large proportion of future coal-fired power stations will be able to be built incorporating the separation and storage of carbon dioxide, a technology that is now viewed with considerably more optimism than just five years ago. It is estimated that the separation and storage of carbon dioxide will reduce the efficiency of the power stations by around 10 percentage points and raise the cost of electricity production by 10 to 20 per cent.

In this scenario, the combined energy supply will be 168,000 terawatt hours, i.e. 15,500 terawatt hours lower than in the IEA's alternative scenario for 2030. This is more than compensated by the production of 46,000 terawatt hours of electricity, which is 50 per cent higher than the IEA forecast: electricity is approximately three times as efficient when used compared to the fossil fuels it replaces.

Thanks to efficiency measures, we expect that energy consumption will not need to increase between 2030 and 2050. Around 30 per cent more efficient use of energy is considered feasible and will be able to compensate for the increasing demand for energy.

After 2050

Developments after 2050 will no doubt be dominated by the continued development of solar power. It is anticipated that the first fusion power station will be ready to be brought on line in around 2050, and will open up interesting opportunities for the future. Tidal water, waves and marine currents also offer considerable potential for producing electricity. Of these, only tidal water power has been able to contribute to electricity production to date: 0.6 terawatt hours during 2007, although the theoretical potential is 300 terawatt hours per year. Wave power has even greater potential, and could theoretically produce between 8,000 and 80,000 terawatt hours per year. Geothermal energy is another possibility, but is not expected to contribute substantially to large-scale energy supply before 2050.

Hydrogen gas is an energy carrier that can be used both in combustion and in chemical conversion to electricity in fuel cells. In this article, the emphasis has been placed on a future electric society, as electricity is more efficient during energy consumption. Hydrogen gas is produced from water, either through electrolysis or through splitting at high temperatures. Hydrogen and oxygen then produce electricity in a fuel cell. It is more efficient to use the electricity directly than to go via hydrogen gas! There are initial energy losses when hydrogen is produced from water with the aid of electricity, and then when electricity is generated and the water is reformed.

One potential method of hydrogen production is through artificial photosynthesis, which could be practicable by around 2050. One of the advantages of hydrogen is its high energy density. Calculated per unit of weight, three times as much energy is obtained from burning hydrogen than from burning petrol. Hydrogen may consequently be of interest in several different contexts, such as for aviation fuel. Alternatively, hydrogen gas together with carbon dioxide can be converted into methanol, or into energy-rich hydrocarbons along with biomass and waste.

The two-degree target achieved with interest

According to the scenario presented (figure 4), the 110,000 terawatt hours of fossil energy that we currently use will fall to 90,000 terawatt hours by 2050, and it is assumed that the carbon dioxide from 10,000 terawatt hours of coal power will be able to be separated and stored underground. On this assumption, annual carbon dioxide emissions from fossil fuels will fall from the current figure of 28 billion tonnes to 20 billion tonnes by 2050. This reduction is expected to continue after 2050 through the continued development of "emission-free" energy sources.

Carbon dioxide emissions from the use of fossil energy over a period of a hundred years will consequently be significantly lower than the 2,200 billion tonnes that are required according to the IPCC's scenarios to achieve the two-degree target – a target that will therefore be achieved with interest in purely technical terms. However, strong measures must also be implemented in relation to deforestation and other sources of both carbon dioxide and other greenhouse gas emissions. Very strong co-ordinated actions will definitely be required from the world's leading decision-makers in order to realise the two-degree target.

Sven Kullander is Professor Emeritus in high energy physics at Uppsala University and at the Royal Swedish Academy of Sciences, where he is Chair of the Energy Committee.

Recommended reading

- David J.C. MacKay. *Sustainable Energy – without the hot air* (www.withouthotair.com).

Storing carbon dioxide – solution or smokescreen?

Both the EU and the rest of the world have great hopes for the technology whereby carbon dioxide is separated and stored. However, there is reason to have a critical attitude, write Anders Hansson and Mårten Lind. There are many uncertainties and little in the way of experience. The critics describe this technology as a smokescreen created by the energy industry in order to continue burning fossil fuels. They feel that the technology is complicated and expensive and the actual storage process is uncertain. Advocates believe that carbon dioxide can be stored safely and that this can be achieved without excessive costs.

Anders Hansson, The Department of Thematic Studies, Linköping University.

Mårten Lind, School of Chemical Science and Engineering, Royal Institute of Technology.

Ever since the industrial revolution, fossil fuels (coal, lignite, oil and natural gas) have been ascribed fundamental importance for industrial development and growth. At the same time, they are the largest sources of carbon dioxide emissions in the global energy system. Most people consider that a modern society without fossil carbon cannot be achieved except in the very long term; meanwhile, extensive measures need to be implemented immediately to counter the greenhouse effect.

Only in recent years has a technology been presented that could handle this contradiction, and that may perhaps make more sustainable coal usage possible. This method is the separation and geological storage of carbon dioxide, known as Carbon Capture and Storage (CCS). This entails carbon dioxide being removed from the flue gases at coal-fired power stations or from other large-scale industrial plants. The carbon dioxide is then transported to a storage location deep underground.

Great hopes

Many people have great hopes for CCS, and development efforts have increased dramatically. The UN's climate panel, the IPCC, considers the CCS to have the potential, during this century, to account for half of the reduction in greenhouse gas emissions that is required in order to achieve the goal of stabilisation at a temperature increase of less than 2 degrees Celsius. Such values should be taken with a grain of salt, as there are many uncertainties associated with CCS. Despite these uncertainties, the European Commission has said that it is not possible to reduce either the EU's or the world's carbon dioxide emissions by 50 percent by 2050 without using CCS. CCS has therefore been included in the EU's new energy package that was adopted in 2009, and will be financed through extensive EU funding during a transitional period, until the technology is fully developed.

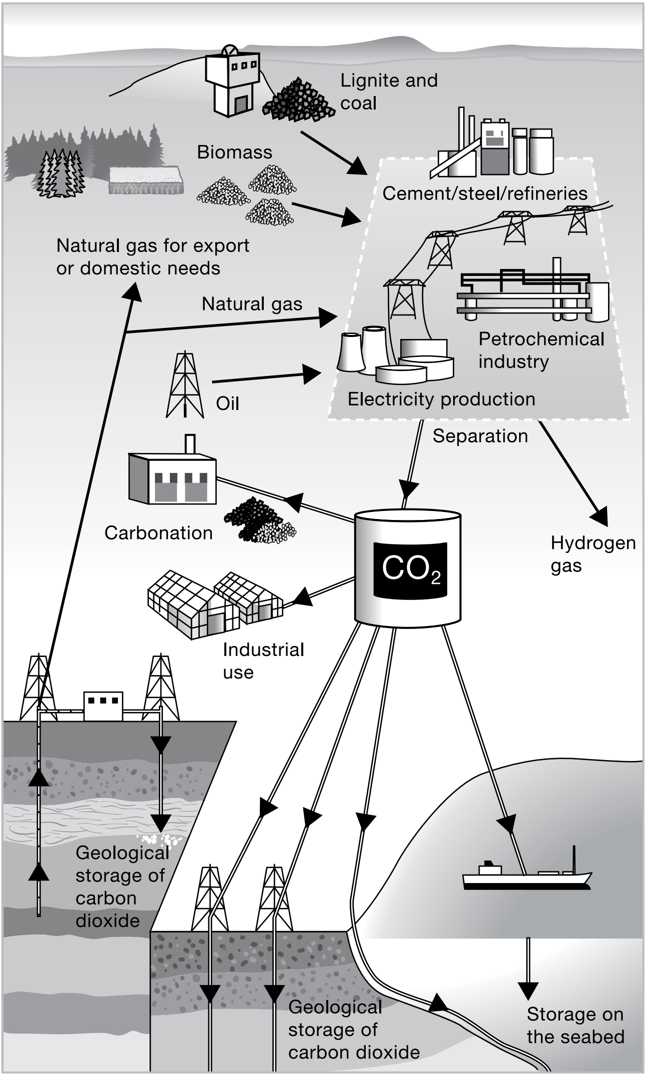
The USA also adopted a stance on CCS a few years ago. One of the reasons for the USA's considerable enthusiasm is that, with CCS, it can continue to use its large domestic coal reserves, the largest in the world, and consequently be less dependent on imported oil primarily from the Middle East. The same argument also carries a lot of weight in the EU. The ability to export CCS technology to developing countries that use large volumes of coal, primarily China, is also a strong argument for CCS. The rapid development of CCS is also justified by the claim that renewable energy does not have the potential that is required to reduce emissions in the short and medium term.

But what does this technology, which has succeeded in mobilising so much support in perhaps a shorter time than any other climate-related technology, actually entail? Are there any uncertainties and risks associated with the technology, and what criticism exists? These are some of the questions we will be discussing.

Profitable for large facilities

CCS comprises three stages: separation, transport and geological storage. Separation cannot be performed on small emissions sources using existing technology; in other words, it cannot be used for cars, lorries or aircraft, for example. In order for the method to be financially profitable, an annual volume of at least 100,000 tonnes of carbon dioxide must be handled. For this reason, the technique refers primarily to coal, oil and natural gas power stations, as

The picture shows possible future CCS systems. The facilities that are primarily suitable for separation are coal, oil and natural gas power stations, as well as major industrial plants such as cement industries, steelworks, refineries, pulp mills and facilities for natural gas processing. The separated carbon dioxide can be stored both geologically, primarily in aquifers and exhausted oil and gas reservoirs, as well as in solid form following carbonation, where the carbon dioxide is bound to various types of mineral such as olivine. Carbon dioxide can also be used industrially to some extent, for example to raise production levels in greenhouses and to manufacture various types of fuel. One example of a fuel is methanol, which can be produced from hydrogen gas and carbon dioxide.



Lignite and coal
Biomass
Cement/steel/refineries
Natural gas for export or domestic needs
Natural gas
Petrochemical industry
Oil
Electricity production
Separation
Carbonation
CO_2
Hydrogen gas
Industrial use
Geological storage of carbon dioxide
Geological storage of carbon dioxide
Storage on the seabed

well as large industrial facilities such as cement industries, steelworks, refineries and natural gas production. CCS can also be used in facilities where biofuel is burned, although this application is not predicted to be as great as for fossil fuels. However, if the global policy focuses on extremely ambitious emissions reductions, the combined use of CCS and biomass may become attractive. This is because such systems facilitate a reduction in the concentration of carbon dioxide in the atmosphere, as biomass itself is considered to absorb as much carbon dioxide as is released during combustion. If the released carbon dioxide is separated and stored, there will be a net reduction in emissions.

There are currently just over 30 locations around the world where CCS or aspects of CCS are being tested, although there are not yet any full-scale CCS plants for power production. Some projects have also been stopped prematurely due, for example, to unexpectedly high costs, a lack of suitable storage locations, public protests or unclear regulations.

Three methods for separation

There are roughly speaking three different types of technology for separation: pre-combustion, post-combustion and oxyfuel combustion. One factor that they all have in common is that they are not commercial at present. As a result, it is not possible to know for certain what their costs and environmental performance will be.

Separation of carbon dioxide pre-combustion takes place after gasification of the fuel and from gas mixtures that usually consist overwhelmingly of carbon dioxide and hydrogen gas. After separation, the principal residue is hydrogen gas, which can be burned for example in a gas turbine. Post-combustion is a process that is based on separation of carbon dioxide from flue gases, for example from coal-fired boilers. Oxyfuel is a technique that Vattenfall is developing at Schwarze Pumpe in eastern Germany, and it has attracted considerable attention worldwide. The technique is based on burning the fuel in pure oxygen from an oxygen plant. The flue gas that is produced consists mainly of carbon dioxide and water vapour. After the water vapour has been condensed to form water, a pure carbon dioxide stream remains that is ready for storage. The various separation methods have been developed to different extents, and are based to varying degrees on previously known, tried and tested techniques.

Depending on factors such as the choice of technique, the quality of the fuel and the potential for cooling, it is estimated that 80–95 per cent of the carbon dioxide can be separated, with the remainder being emitted as normal. A power plant with CCS also requires 10–40 per cent more fuel to produce the same amount of electricity as a plant without CCS. The consequence of this is that there is a difference between the amount of separated carbon dioxide and the amount of carbon dioxide kept out of the atmosphere. More fuel has to be used, with the result that it is not only the fuel cost that increases, but also the environmentally harmful coal extraction. Coal extraction in turn produces emissions of the powerful greenhouse gas methane. If this is included in the calculation of the emissions from a CCS plant, the amount of greenhouse gases kept out of the atmosphere may only be as low as 65 per cent, a fact that many critics are careful to point out.

Expensive smokescreen

As a result of the increased fuel requirement for CCS, as well as investments in technical equipment, electricity production costs will be higher. Depending on local conditions and the choice of technique, this can range from approximately 20 per cent higher to almost twice as much. The current high costs are viewed by many as the greatest obstacle to CCS being able to be developed at all.

Even when CCS is a mature technology, it may be extremely costly to implement retrofit-installations.

CCS is therefore primarily intended to be installed in conjunction with the construction of new power plants. As power plants are extremely expensive, in the region of SEK 10 billion (roughly 1 billion euro) per plant, and have a lifetime of 30–60 years, it could take a long time before CCS is installed in the majority of plants. Critics often point out that there is a risk that CCS will result in the construction of coal-fired power stations that would otherwise not have been built, and that it is risky to rely on a technology that has not yet been sufficiently tested. CCS is therefore sometimes described as a smokescreen that the energy industry has created in order to continue burning fossil fuels in more or less the same manner as before.

When the carbon dioxide has been separated, it must be transported. Pipelines or boat transport are the most suitable methods for transporting large volumes of compressed carbon dioxide. They facilitate the transport of carbon dioxide over hundreds of kilometres, even across national borders, for subsequent storage. Carbon dioxide has been transported in pipelines since the 1970s and is considered by most as relatively unproblematic from a technical perspective, and appears to entail risks that are at an acceptable level. These risks are considered to be comparable with those associated with the transport of natural gas in pipelines. The costs for reasonably long-distance transport are small compared to the costs for separation, which is by far the most costly element of CCS.

Stores can leak

There are three different geological storage methods: in oil or gas reservoirs, in deep groundwater reservoirs known as aquifers, and in unminable coal seams. If CCS makes the major breakthrough that the IPCC has anticipated, somewhere in the region of 220 to 2,200 billion tonnes of carbon dioxide will need to be stored this century. If this were to be the case, the carbon dioxide that is processed in CCS systems could become the world's largest commodity. The issue of storage is the area where the greatest scientific uncertainty lies.

The global storage space is estimated to be larger than will be required, and the potential storage locations are relatively evenly distributed around the world. However, as each storage location has unique geological conditions, it is difficult to determine the accuracy of this information, which comprises estimates and is not based on actual measurements and tests other than in a few individual cases. Another aggravating circumstance is that the carbon dioxide must be stored for many hundreds or thousands of years if the method is to be effective. A quick calculation shows for example that if 1 per cent leaks out each year, 63 per cent of all the carbon dioxide will have leaked out after a hundred years.

A great deal of research is currently being conducted regarding storage. Carbon dioxide is being injected into the ground in many places and will subsequently be monitored. This research has been criticised as not being sufficiently objective, as the trials to try to demonstrate that the carbon dioxide remains below ground are primarily being carried out only under ideal conditions and for relatively short periods of time. In Norway, however, a decision has recently been taken to conduct studies on poorer storage sites, where a leaking store near Drammen will be monitored to observe what happens during the actual leakage process. This is important from a safety perspective, as it is not possible to determine with absolute certainty in advance whether a store will be secure or not. It may be necessary to have remediation strategies in place to capture the carbon dioxide again in the event of any leakage.

The storage takes place at depths of more than 800 metres, where the pressure and the temperature cause the gas to change into a dense phase. Once down in the ground, the durability of the gas depends on a combination of physical and geochemical confinement mechanisms. In ideal cases, there will be a seal comprised of practically impenetrable clay and shale above the storage space. If such a seal is absent, the risk of the carbon dioxide spreading increases. However, there are other physical and chemical mechanisms that will hold the carbon dioxide in place. For example, the carbon dioxide may be dissolved in any water that is present in the formation, causing its density to increase. This in turn results in the carbon dioxide-containing water to sink to the bottom of the formation.

Other risks

In addition to the risk of a small leak that makes the process pointless from a climate perspective, there are risks to the surrounding environment in the event of a major leak. For example, accidents can occur during the actual injection process. It is considered that these could be dealt with quickly using tried and tested techniques, such as those used at present by the oil industry for blow-outs. Slow leaks that primarily affect drinking water and ecosystems are also possible. The ground could be acidified, as carbon dioxide itself is slightly acidic. In marsh areas or when there is no wind, people and animals could also be injured. Most experts consider these risks to be very small, but that does not mean that these issues are insignificant for the people living in the vicinity of storage sites, both now and in the future. Many possible storage sites are also located in densely populated areas. Researchers and the energy industry are currently looking into the way in which the public will react to CCS under such circumstances.

CCS is one of the least known climate measures among the general public, and it does not enjoy particularly wide support. In the 20 or so scientific opinion polls that have been conducted in Western Europe, the USA, Canada, Japan and Australia, most citizens have stated that they prefer renewable energy when faced with the suggestion of building CCS. Some researchers have demonstrated what can be referred to as "reluctant acceptance" of CCS among the public. This means that the technique is often considered to be a necessary evil when CCS is compared to rampant climate change. It is not only the risks associated with storage that cause attitudes to be relatively negative, but also the risk that CCS may have a negative impact on investments in renewable energy, since CCS entails the continued use of fossil fuels. This is also one of the primary objections from some sections of the environmental movement.

CCS technique a partial solution

CCS advocates often emphasise that the large-scale use of coal will continue and perhaps even increase for several decades to come. For example, 90 per cent of the increase in electricity production capacity in China in recent years has been based on lignite and coal, as the country has such large coal reserves. If the industrial expansion continues at the same rate, the development of coal power in China will exceed the combined electricity production capacity of the USA and the EU. Satisfying this enormous energy requirement is considered by most to be difficult or even impossible without the use of fossil fuels. A continuation of this trend is a nightmare scenario from a climate perspective, at the same time as being viewed by most as a precondition if industrial and economic development is to be able to continue as it has done to date.

CCS is an attractive alternative if we consider that the technique can be developed quickly enough, that the carbon dioxide can be stored safely and that this can be done without excessive costs. The critics, who are significantly fewer in number than the advocates, believe on the other hand that CCS will not be developed in time. They also consider CCS to be too technically complicated, too expensive and that it is not ethically defensible to store waste (carbon dioxide) for which future generations will have to be responsible. They therefore feel that it is better to invest right now in cheaper, tried and tested, renewable technology and energy rationalisation.

CCS does not necessarily entail a clash of interests between renewable energy and retaining fossil fuels with CCS. Most experts, even within the environmental movement, consider that CCS may be one of many partial solutions. The question of CCS's future cannot be answered for certain yet, as there are still many areas of uncertainty and little practical experience. In other words, there are good reasons to maintain a critical approach to CCS and notions of its future significance.

Anders Hansson is a researcher at the Centre for Climate Science and Policy Research at Linköping University. He has written a doctoral thesis on CCS and conducted research regarding CCS in EU projects. His primary focus relates to the social science aspects of CCS, such as scientific uncertainty and the CCS debate.

Mårten Lind holds a PhD from the School of Chemical Science and Engineering at KTH – Royal Institute of Technology in Stockholm. In his PhD thesis he has for example looked at various technical alternatives for the separation of carbon dioxide. He also has an interest in laws and regulations concerning CCS, and has been responsible for a work package within the EU project STRACO2.

Carbon dioxide storage – an essential element in tackling global climate change

If global climate change is to be addressed seriously, we need to reduce carbon dioxide emissions using all available technologies, including capture and storage of carbon dioxide (CCS). Given the large reserves of fossil fuel that remain to be used, failure of CCS would be a nightmare scenario. However, the outlook of this technology looks bright. In the long term, it will be important to establish a global price for carbon dioxide emissions that is sufficiently high to ensure that CCS and other technologies will be implemented on a large scale, writes Filip Johnsson.

Filip Johnsson, Department of Energy and Environment, Chalmers University of Technology.

Do we need to capture and store carbon dioxide? Undoubtedly the answer is yes. The large reserves of fossil fuels represent the main threat to the climate on this planet – a point that seems obvious but that is often overlooked. The exploitation of the large fossil fuel reserves appears to be inevitable, particularly over the next few decades. Moreover, we are currently witnessing a substantial increase in the use of fossil fuels in the developing economies of Asia, particularly in China which has large reserves, primarily of coal. The consequence of this elevated consumption of fossil fuels is a corresponding increase in carbon dioxide emissions.

Against this background, one realises that successful development of technologies, which facilitate continued use of fossil fuels such as coal, oil and gas without any additional carbon dioxide emissions into the atmosphere is crucial to achieving climate preservation goals. We are facing the enormous challenge of meeting the two-degree target, which states that the Earth's average surface temperature may not rise by more than two degrees above the pre-industrialized levels. This means essentially that by 2050, the richer regions of the world have to reduce their carbon dioxide emissions to zero. Since, to achieve this goal, global emissions have to fall by between 50 and 85 per cent from the current level, it is unreasonable to expect the developing economies to undertake emission cuts as large as those demanded of the rich countries of the world. The carbon dioxide emission levels of the developing countries are also to a large extent linked to high levels of consumption in the West. Approximately 80 per cent of energy supplied currently comes from fossil fuels, and there are large reserves of these fuels, primarily of coal. Therefore, substantial investment is being made worldwide in the research and development of technologies for capture, transport and storage of carbon dioxide. Intensive research and development of all three stages in this process are currently underway (see figure in previous chapter).

Price of emissions required to get wide scale introduction of CCS

Carbon Capture and Storage (CCS) is attractive because: 1) large storage capacity for carbon dioxide is available at many sites around the world, 2) it is unlikely that the carbon dioxide will leak out, and 3) the technology is potentially cost-effective, assuming of course that a price is established for carbon dioxide emissions. If we are to achieve substantial reductions in emission levels of greenhouse gases, the release of carbon dioxide must be linked to monetary penalties. Then, we will most likely see the application of all available technologies and measures to curb climate change: adoption of renewables, increased energy efficiency, energy savings measures, CCS and nuclear power.

The positive aspect is that the cost of addressing climate change is not particularly high relative to the anticipated level of economic growth or compared to the costs that are expected to arise if we fail to implement any counteractive measures. The main challenge is a political one – to agree on consensus for pricing emissions of carbon dioxide and other greenhouse gases. Successful development of CCS is important, as it will make it easier for fossil-dependent regions to make significant commitments regarding emissions reductions.

CCS infrastructure is a decisive factor

Although considerable research and development efforts are required over the next decade to ensure that CCS works efficiently, the major challenge lies in quickly establishing an effective infrastructure for capture, transport and storage of carbon dioxide, thereby controlling costs and guaranteeing that CCS is adopted on a large scale. The necessary infrastructure comprises new power plants that incorporate carbon capture, systems of pipelines for transporting the captured carbon dioxide, as well as storage sites that have injection systems for the carbon dioxide.

These are large systems that require extensive planning, and the development process may take many years. In addition, monitoring equipment will be needed to ensure that there is no leakage of carbon dioxide. Regulations specifying the requirements for carbon dioxide storage, e.g. the purity of the carbon dioxide, will also have to be drawn up. In Europe, a new directive outlines the general requirements for carbon dioxide storage. At present (2009), this directive is being adapted to the environmental legislations of the various EU member states.

Most experts believe that CCS will be available commercially by around 2020, i.e. in around ten years. Therefore, in the period after 2020, significant expansion of an integrated CCS infrastructure must occur. Considerable investment in the electricity production sector is required over the coming decades, and this constitutes an opportunity to plan for the implementation of CCS. However, it is not clear what will happen with the investments that have to be made before 2020. For example, coal-fired power plants in North America (USA and Canada) are ageing, and many of the coal-fired power plants in Europe will have to be replaced before 2020, i.e. before CCS is expected to be commercially available. Of course, some of these plants may be replaced with renewable electricity generating facilities, but in many cases the plants that need to be replaced are baseload plants with large installed power where the alternative is often to replace coal plants with natural gas fired plants. This can result in Europe and regions in the US becoming locked into an already significant dependence on natural gas. In recent decades, Europe's electricity generating sector has become increasingly dependent on natural gas that is imported from a few countries outside the EU, while the EU's own natural gas deposits are nearing depletion. Coal is both a domestic resource (particularly in those countries that have lignite) and a commodity that can be purchased on the global market from suppliers in various countries.

In Asia, it is important to commence the development of CCS as quickly as possible so that the immense domestic resources of coal can be used in power plants equipped with carbon capture. Therefore, it is important for Europe and the USA to take the lead in demonstrating the feasibility of applying CCS at a reasonable cost. The first coal-fired power plant to be built "without a chimney" will have a strong symbolic value, in that it will subsequently be difficult to justify the construction of coal power plants without capture of carbon dioxide.

Where will we see CCS applied first?

CCS is expected in the first instance to be cost-effective in large (around 1 000 megawatts) coal fired power plants that are running in baseload. Especially lignite (“brown coal”) is a low cost fuel and in Europe this fuel is often burned in high efficient power plants with state-of-the-art flue gas cleaning resulting in low emissions of harmful products such as nitrogen and sulphur oxides, but of course with high emissions of carbon dioxide. Typically, such power plants may have an electric efficiency of around 43 per cent but this could be increased to some 48 per cent, still using available technology. Future plants may reach 50 per cent. Considering typical energy penalty from carbon capture of 7 to 8 per cent (in absolute terms) would result in that first commercial application of CCS plants around 2020 may very well have an electric efficiency similar to that of current coal plants without capture (more than 40 per cent). Yet, first capture projects applying present technology or applied on existing plants (adding so called post combustion capture) will lead to lower efficiencies and thereby higher capture costs (per tonne of carbon dioxide captured).

As indicated above, the main driving force for implementation of CCS is a cost of emitting carbon dioxide. In Europe, there is the Emission Trading

System (EU ETS), which has been in place since 2005, which is expected to over time give an increased cost of emitting carbon dioxide. In USA and Japan recent (2009) change in government has made it more likely that similar schemes will be implemented in the US (the Waxman-Markey bill) and in Japan (new government has expressed willingness to implement an emission trading scheme). Yet, it is likely that it will take more than 10 years before CCS will be commercially available in the sense that the cost to avoid carbon dioxide emissions by means of CCS will be lower than the cost to emit carbon dioxide (e.g. through the EU ETS). Thus, support schemes must be put in place in order to boost the development of CCS over the next decade. In Europe, the EU has initiated work to establish a network of demonstration projects across Europe, as well as a joint initiative with China to develop and deploy the CCS technology. At present, most of the plans for large scale CCS demonstration projects are in Europe and North America and it seems reasonable to assume that large scale application of CCS will first be applied in these regions.

Depending on how much it will cost to emit carbon dioxide in future emission trading schemes, CCS can also be applied to various industrial processes (such as cement, steel and refineries). Although costs for transport and storage is much lower than the cost for capture this is provided there are large integrated networks of transport and storage serving clusters of large power plants and industries. Thus, the “ramp-up” of a CCS infrastructure is critical, since transporting and storing carbon dioxide from a single facility will be considerably more expensive (per tonne of carbon dioxide stored) than from several plants in an integrated transport and storage infrastructure. To limit transport and storage costs, it should be of importance to establish partnerships between various actors involved in the CCS chain (capture, transport and storage) in order to establish an integrated CCS infrastructure.

Indirectly, CCS may also be of interest for the automotive industry. Increase in price of oil, combined with increased focus on security of supply and the large global reserves of coal, mean that fuel production from coal constitutes yet another threat to efforts to reduce carbon dioxide emissions; plants of this type are already being planned and built in China. An alternative is an increased use of electric cars that employ plug-in hybrid technology. Thus, the part of the electricity that is produced from coal or gas can take place in power plants employing CCS technology. Such a system could also be used to increase in a cost-effectively manner the fraction of wind power (and other intermittent electricity generation) by smoothing the variability in wind power generation with charging or discharging of the car batteries. Thus, there should be considerable opportunities for the automotive industry to develop new technical solutions and vehicle systems for a climate-smart transport system. For example, the Swedish utility company Vattenfall and Volvo cars collaborate within the field of developing plug-in hybrid vehicle systems. In the future the boundary between the stationary energy system (production of electricity and heat) and the transport sector is likely to be broken up through such collaborations between the automotive industry and electricity producers.

Will CCS be accepted?

New technologies, such as CCS, often encounter problems with acceptance. Studies of public attitudes to CCS show that the general public is largely unaware of the technology, so it is currently difficult to assess the degree of acceptance. However, introductory pilot and demonstration projects have met local resistance.

It seems likely that the inhabitants of regions that are directly dependent on fossil fuels will feel more positively about CCS than persons who live in regions that are not dependent upon or that not perceived as being dependent upon these fuels. In regions that have coal deposits (such as lignite), the application of CCS may entail replacement of an old power plant with a new one, while retaining jobs. The storage part will no doubt be controversial in certain cases, although significant storage potential exists offshore (i.e. under the seabed) far from inhabited areas.

Failure of CCS a nightmare scenario

If climate change is to be addressed in a comprehensive way it is imperative that all possible technologies and measures are used to reduce carbon dioxide emissions. Therefore, it is not a choice between wind power and CCS, rather we need both of these technologies, just as we need substantial increase in energy efficiency, employment of energy savings, development of solar and wave power as well as some nuclear power.

The failure of CCS development would be a nightmare scenario, bearing in mind the remaining extensive fossil fuel reserves, particularly in those countries that produce most of what we in the west consume. At present, developments are pointing towards CCS being successfully demonstrated in the near future, with a large number of development projects in progress. In the long term, however, it is important that a sufficiently high price be set for carbon dioxide emissions, so as to facilitate the introduction on a large scale of CCS and other technologies.

Filip Johnsson is Professor of Sustainable Energy Systems at Chalmers University of Technology. His research covers various aspects of the production, distribution and use of electricity and heating. The focus is both on thermal conversion of various solid fuels for power and heat production, as well as energy systems analysis in which various development pathways for Europe's energy systems are studied. His research includes the combustion and gasification of biomass, as well as carbon capture from coal combustion using the oxyfuel technique.

Recommended reading

- As developments are taking place rapidly, it may be a good idea to search on the Internet for e.g. "carbon capture and storage", "geological storage of CO_2", "CCS" and to look at various links.
- A considerable amount of information can be found on the IEA's website (International Energy Agency; www.ieagreen.org.uk), from where fact sheets can be downloaded.
- For Europe, see: http://ec.europa.eu/environment/climat/ccs/index_en.htm
- For USA, see: http://www.fossil.energy.gov/programs/sequestration/

Global climate ethics – what is at stake?

Global justice as regards the climate – is this possible? What is most important: for benefits and burdens to be shared equally, or for everyone to participate in climate policy decisions? Or is there a third way? The most important thing is perhaps to discuss what is at stake for people in different parts of the world, writes David Olsson Kronlid. Ethical research has a great deal to contribute to the climate negotiations.

Photo: Peter Jonsson, Sundsvalls Tidning

David Olsson Kronlid, Department of Curriculum Studies, Uppsala University.

How are climate change and justice linked? Why is it relevant to discuss moral issues when we have to deal with the enormous challenge of handling issues relating to global warming, emissions credits and adaptation to climate change? The climate issue is viewed in the first instance as a matter for scientists and engineers. The question is what can humanistic research contribute. I will try to explain why moral issues are relevant to the climate issue, discuss which moral challenges have attracted the most attention in the climate debate, as well as what ethical research can contribute to future climate negotiations.

The mass media's coverage of the consequences of climate change has increased significantly. Just ten years ago, there were still discussions among scientists, politicians, journalists and educators as to whether man was causing climate change. Nowadays most people agree that climate change is principally due to our own emissions of greenhouse gases. In addition, more and more are claiming that, in addition to being a scientific, technical, medical and economic issue, climate change is also a moral issue.

Various individuals have pointed out on different occasions that the climate issue is fundamentally a moral one, including professors at Swedish universities, the former head of the IPCC, Bert Bolin, the former US presidential candidate, Al Gore, the former chief economist of the World Bank, Nicholas Stern, and Lena Asking, editorial writer on the Swedish newspaper Aftonbladet. Their argument for this is that climate changes are causing considerable suffering among people, and that people who are already subjected to major trials and tribulations, particularly in poor developing countries, are affected and will be affected most by the consequences of climate change.

Slow and fast effects

What types of suffering are we talking about here? Firstly there are the slow effects of climate change on people's lives. On the Worldwide Fund for Nature's website, we can read Tulsi Khara's account of her situation. She has lived for 70 years in the Sundarbans Delta, where the Ganges and the Brahmaputra meet and flow out into the Bay of Bengal. For her and her family, climate change has resulted in steadily rising water levels that have swallowed up the majority of her two hectares of land. It is not difficult to see that this might be a disaster for a family that is dependent on its land for its survival and that is financially, ecologically and perhaps also socially vulnerable.

Another long-term or indirect climate effect is the impact of climate change on traditional knowledge systems. Both scientists and representatives of indigenous peoples bear witness to the fact that a changed climate threatens the ability to predict weather changes, for example.

Alongside this slow effect, there are also fast or direct effects of climate change, including the increased occurrence of natural disasters such as Hurricane Katrina, which struck the inhabitants of New Orleans. Images of helpless people wandering through mud and water in their living rooms have been burned into our minds. Katrina has had a serious impact, primarily on poor people's potential to go to school, have access to healthcare, have access to mobility recourses, having functioning accommodation, and so on.

Suffering consequently follows in the wake of climate change. Sometimes this negative change in people's lives is slow and creeping, sometimes it rips the roofs off our houses in a couple of seconds. We feel for people who are affected in this way. But it is not just human suffering that links climate and moral issues. Natural phenomena such as storms, droughts and floods are among the preconditions for life. One thing that makes the consequences of climate change a moral issue is that it is not spontaneous changes in nature that cause suffering, but rather people's actions. In addition, those of us who are not affected as much by this suffering have the potential to do something about the matter, for example by reducing our own emissions, but also by helping those who are particularly affected to adapt to the new challenges they are facing.

Climate justice dominates climate ethics research

The international community is focusing on two areas in order to meet the considerable suffering that climate change is causing: increasing knowledge about the climate and its consequences, and drawing up international agreements. Ethical research can contribute to both of these areas. Compared to other climate research, there is very little about climate ethics research in the climate literature. The research that exists is dominated by a discussion about climate justice. So what is meant by climate justice?

The discussion that has been conducted focuses on "equity". Equity is often combined with another common term within discussions about justice, namely distribution. As a result, the most prominent idea within research into climate and justice can be described as: *Climate change's negative and positive consequences should be distributed equitably between the world's nations and peoples.*

Such an attitude is known as distributive climate justice. Nobody should bear more or heavier burdens than anyone else, or draw more or greater benefits from changes to the climate, unless such distribution is considered just. A distributive approach to climate justice suggests for example that it is unfair that Tulsi Khara from the Sundarbans Delta loses most of her land while landowners in Western Norrland in Sweden do not lose any of theirs. This may be considered unjust, as we have all contributed and are contributing to climate change to a lesser or greater extent.

General participation in climate policy decisions

But is it really so simple that all we need to do to achieve climate justice is to ensure that we share out suffering, happiness and responsibility equally? The answer is that there are many different arguments when it comes to what climate justice can be. I will mention at least two more ways, one of which is a suggestion for how we could formulate a global theory of climate justice.

Alongside distributive justice, research is also being conducted into procedural justice. This means that a society is only fair when everyone has the same opportunities to participate in political decisions and when everyone's votes are considered equally important. If we transfer this to our discussion on climate justice, it entails the following: *The decisions that relate to how we should handle the negative and positive consequences of climate change should be made on the basis of a discussion in which everyone who is affected by the decisions may participate on equal terms.*

Just consider the example of Hurricane Katrina again. The issue of whether New Orleans is a just society or not would depend on the extent to which those who were affected by Katrina are able to participate in the political decision-making process on equal terms, irrespective of their education, economic status or political power.

The concept of climate justice is consequently not obvious. Different climate justice models can result in different political decisions. Before I say anything about what climate ethics research can contribute to future climate negotiations, I will discuss a concept of climate justice that combines the idea of equitable distribution of climate change's burdens with the idea of equal access to climate policy decision-making.

Towards global climate ethics?

Climate changes are global, and the consequences are distributed around the whole world. Bearing this in mind – and in line with the ambition of trying to agree on international, legally binding agreements on emissions – it is natural to talk about the need for global climate ethics. This would entail a set of moral principles or standards that all or most of us can accept and that can help us in our decisions about the future.

One problem that we are immediately faced with is that the perceptions of what is moral and immoral seem to differ from person to person, place to place, culture to culture and community to community. How can we formulate ethics that everyone will accept if we have different ideas about what is moral and immoral? My answer to this question is that we need a concept of climate justice that, on a general level, is sufficiently open that people in as many cultures as possible might accept it, at the same time as being able to be interpreted differently in different locations without its fundamental concept being lost.

One way of deciding what a climate-just society might look like is to try to understand what is actually at stake, for example for Tulsi Khara and the inhabitants of New Orleans. What is being fundamentally threatened in their lives or even destroyed by the consequences of climate change? In answer to this question we can say that they are losing their assets, and this is a reasonable answer. Above all, however, they are losing the tangible opportunities to live the lives they want to live.

As Tulsi Khara is losing her land, this is primarily threatening her *abilities* to choose how she wants to provide for herself, and consequently limiting her potential to choose how to spend her old age. Poor people in New Orleans are not only losing their houses, cars and other assets. Above all, they are losing the potential to move about as they wish, their potential to work, to acquire education, to meet the people they want to meet and to participate in the political contexts they want.

Equitable distribution of opportunities

If we transfer this to our discussion on climate justice, it entails the following: *In order to determine whether the negative and positive consequences of climate change are unjust or not, we should look at how they threaten or affect people's fundamental abilities and functionings.* In other words, instead of talking about climate justice in terms of how suffering and benefits should be distributed, or in terms of whether we are able to participate in political decisions on equal terms, we can talk about climate justice in terms of fundamental capabilities.

This is an abstract argument, and we have to remain on an abstract level initially in order to develop a "climate justice language" that can be applied to different locations, in different economies and cultures. In the next stage, it is important for people themselves to define what is important for them in relation to climate change, and which of their tangible capabilities are being threatened. After all, it is not access to the same or any specific opportunities that ought to be distributed equally. The opportunities that are considered important change from case to case, from individual to individual, and differ depending on whether you are living alongside the Ångermanälven River in Western Norrland in Sweden, in the Sundarbans Delta in India or in New Orleans.

When we are affected by climate change, it appears primarily to be our abilities to live the lives we want to live that are threatened and diluted. This is something that everyone has in common, regardless of *how* we are affected and *where* we are. Having the opportunity to live the life you want to live is a fundamental driving force in all people, no matter where we live. You, me, Tulsi Khara and Al Gore are entitled to reasonably similar opportunities to live the lives we have reason to value.

Accordingly, if this is a reasonable thought, then we have a concept of climate justice that hopefully many can accept, regardless of where they live, their religion and their culture. I therefore believe that the concept of climate justice in terms of opportunities (*Climate Capabilities*) is a good candidate in the hunt for global climate ethics.

Climate ethics and climate negotiations

So what can ethical research contribute in future climate negotiations? The obvious answer is that we need climate research that can help us to understand the many different dimensions of climate change. This is particularly true when the climate change affects our economic, ecological and social opportunities to lead dignified lives. In addition, the climate issues incorporate many different conflicts of interests and values between different parties. The climate is about more than just figures and statistics.

It is reasonable for those sitting around the negotiating table to have decision-making data that is as accurate as possible. Ethical research can contribute by clarifying various aspects of climate justice. However, it is also important for the ethical research to clarify the reasoning and views of people whose opportunities for a good life are threatened by climate change. Such empirical ethical research can help to formulate global climate ethics and to provide the negotiators with a greater insight into perhaps the most important question of all: What is actually at stake?

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Rio, Kyoto, Bali, Copenhagen – climate collaboration in the melting pot

The climate issue is a hot topic in top-level politics and international negotiations. What requirements should be stipulated regarding emission reductions? How should the burdens be shared? What principles should apply? Björn-Ola Linnér and Bo Kjellén paint a picture of international climate co-operation – from Rio to Copenhagen. If the results from Copenhagen in December 2009 are weak, we will probably have a debate about the Climate Convention. Is the UN route the right one? Is there too much market and too little political control in today's climate work?

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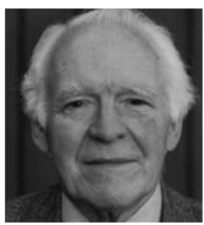

Bo Kjellén, Stockholm Environment Institute.

Climate change is a global problem – it doesn't matter where greenhouse gases are emitted, they end up in our shared atmosphere and have consequences all around the world. For this reason, international collaboration has become a natural response to the challenges. However, the efforts to find global solutions are not uncontested. Here we present the emergence of global climate negotiations and discuss some of the challenges they are facing.

The climate issue, which initially was only discussed by scientists, experts and some environmental campaigners, has become a major political issue in the space of a couple of decades. It is now on the agenda at top-level meetings and is discussed by Presidents and Prime Ministers. It also has major economic and social consequences, with the result that it is at the heart of what has been termed new diplomacy, characterised by the way people will be able to meet new types of threat that cannot be unequivocally tied to an individual nation or coalition of countries.

The Climate Convention

It was not until the end of the 1980s that warnings from scientists resulted in action on a diplomatic level. This occurred in conjunction with the major convention on the environment and sustainable development that was held in Rio de Janeiro in 1992. All global environmental problems were on the agenda. This was the UN's second major environmental conference – the first had been held in Stockholm in 1972.

The UN's General Assembly decided that negotiations should be conducted regarding a Convention to tackle the climate threat, and these began in early 1991. These negotiations were complicated and difficult, and under significant time pressure, as the aim was for the Convention to be signed at the Rio conference. The negotiating rooms were the site of intense wrangling. Many of the delegates were still fairly unfamiliar with the problems, and as large financial and social interests were at stake, many countries were reluctant to go all that far to meet threats that still seemed diffuse and difficult to assess. However, after extensive efforts, they managed to arrive at a Convention that could be signed in Rio by 153 countries and that entered into force in 1994. The Convention now has more or less global coverage, with 192 countries having signed up.

The goal of the Convention is to stabilise the concentrations of greenhouse gases in the atmosphere at a level that prevents harmful human impact on the climate system. The Climate Convention covers all greenhouse gases that are not regulated in the Montreal Protocol on the protection of the ozone layer. It contains provisions stating that the absorption of greenhouse gases through sinks must also be taken into consideration, such as absorption by forests. The Convention only contained limited concrete commitments, but it built a framework and created procedures for continued collaboration.

The Kyoto Protocol

Right from the very first meeting of the parties to the Convention, it was established that more specific commitments were required, and the decision was made that a separate, supplementary protocol should be negotiated. These negotiations made it possible for the Kyoto Protocol to be adopted in the late autumn of 1997. It was now possible to agree that industrialised countries should reduce their emissions of greenhouse gases, primarily carbon dioxide, by an average of just over five per cent compared to 1990 levels at the latest by 2012, according to a scale whereby different countries had different obligations: the EU countries as a group were to reduce emissions by 8 per cent, the USA by 7 per cent, Japan by 6 per cent, and so on. The developing countries did not need to make any specific commitments of quantifying emission limitations. The Protocol also contained a series of other regulations, for example regarding the transfer of technology to developing countries, adaptation measures and the establishment of trading in emissions credits. These were very modest measures, but it nevertheless proved difficult to get important countries to approve the agreement.

In spring 2001, the USA decided not to ratify the Protocol. This paved the way for a crisis within the work, as it was necessary for industrialised countries responsible for at least 55 per cent of the group's emissions in 1990 to be involved. The USA had been responsible for 36 per cent of emissions at that time, so there was only a small margin. However, the EU accepted the challenge and declared that the Union would ratify the Protocol and work in various ways to ensure that other countries would become involved. There was a significant delay as another key country hesitated for a long time, namely Russia, which was responsible for 17 per cent of the emissions. In autumn 2004, however, Russia ratified the Protocol, which was then able to enter into force in February 2005. By July 2009, the Kyoto Protocol had been ratified or otherwise approved by 186 nations.

International climate collaboration after Bali

The Protocol's commitments run until the end of 2012. Over the past few years, negotiating groups, decision-makers and scientists have been discussing the architecture of the next climate agreement. Following at times difficult discussions at the Climate Convention's meeting in Bali in December 2007, the parties also agreed an agenda for continued negotiations leading up to the decisive meeting in Copenhagen in 2009. Two central challenges for the Climate Convention now are to get the USA involved in commitments once more, and to create a basis so that large developing countries such as India, China and Brazil can also make measurable commitments regarding reducing emissions of greenhouse gases.

We would like to highlight six issues that are influencing both the potential to reach agreement and the effectiveness of the agreement: 1) the rate of reduction, 2) the Climate Convention's building blocks, 3) adaptation measures, 4) efforts for sustainable development, 5) the scope of market-based solutions, and 6) principles on which the agreements rest.

Rate of reduction

There is explicit consensus among the parties to the Climate Convention that, in the long term, we have to reduce emissions of greenhouse gases radically. The agenda from Bali establishes that the fourth assessment report from the UN's climate panel, the IPCC, should form the basis for the next agreement. In order to achieve the IPCC's lowest stabilisation scenario, whereby the temperature increase is limited to between 2 and 2.4 degrees during this century, it is necessary for emissions to reach a peak no later than 2015 and thereafter to fall by between 50 and 80 per cent by 2050. It is not granted that this scenario will form the basis for the work. At the G8 meeting in July 2009, however, attended by eight of the world's leading industrialised nations, an important indication was given. Together with five of the largest economies among the developing nations (Brazil, the People's Republic of China, India, Mexico and South Africa), the G8 decided to work on the basis of the two-degree target that the EU has advocated for many years. In other words, that the global increase in temperature should, on average, be restricted to two degrees Celsius compared to the situation prior to the industrial revolution.

In order to achieve this goal, the G8 decided to reduce the rich countries' emissions by 80 per cent by 2050 compared to 1990 or later. Politicians are sometimes accused of having a horizon that only extends for one term of office. The international climate policy shows that deciding how much emissions should reduce within the next two to three terms of office is extremely difficult. Where emissions will be in 2020 is one of the difficult questions prior to the next climate issue. The EU has stated that it is prepared to reduce emissions by up to 30 per cent by 2020 compared to 1990 levels, if there is a general agreement. Otherwise the aim is restricted to a 20 per cent reduction. A draft bill in the USA, on which the Senate is expected to vote in early 2010, proposes a reduction of 17 per cent by 2020 and 42 per cent by 2030 compared to emissions in 2005.

The Climate Convention's building blocks

The Bali meeting agreed that the next agreement period must build on at least four central elements: a reduction of greenhouse gases, adaptation to climate change, financial support for measures in developing countries and the transfer of technology from industrialised countries to developing countries.

A future climate agreement must include a greater focus on adaptation, as the consequences of climate change are already being experienced and poor people have to bear a disproportionately large share of the burden. More funds are required for national adaptation programmes and extremely vulnerable nations, for example by reinforcing the existing adaptation fund. Another proposal that to date has not received much support is to distribute responsibility for financing adaptation in developing countries by calculating historical responsibility for emissions of greenhouse gases.

Financial support and the transfer of technology are two issues covered by prolonged discussions over several decades within the international co-operation on sustainable development. This is due in part to the fact that there is an obvious conflict between countries' trade interests, companies' competitive advantages and intellectual property rights. One important point that the developing nations succeeded in adding to the agenda from Bali was that efforts regarding the four building blocks should be able to be measured, reported and verified. In this way, it is hoped that rich countries will move from friendly words to action when it comes to the transfer of resources. An additional building block is also being added: reduced deforestation and forest destruction. Negotiations are currently in progress regarding how new planting and replanting of forests, forest management and agricultural methods can be counted as measures to increase the absorption of greenhouse gases. For some developing countries, such as Indonesia, this is extremely important in order to facilitate their future commitments to reduce emissions of greenhouse gases into the atmosphere.

Links between climate and sustainable development

In order to reach a global support for environmental agreements, a central element ever since the Rio conference in 1992 has been to see how development goals and environmental goals can be brought into line with each other. Within the research, analysis is being conducted regarding the extent to which these goals support each other, as well as the extent to which we have to make compromises between environmental considerations, economic and social development. Even though the importance of coordinating climate efforts with sustainable development was emphasised in the 1992 Climate Convention, climate policy for a long time remained primarily a matter for countries' Ministries of Environment.

Since the meeting of delegates in New Delhi in 2002, the climate issue has increasingly gone from being primarily an environmental issue to being a negotiation on efforts towards sustainable development. This focus can be seen from the fact that the Climate Convention's architecture is increasingly being shaped through a number of connected issues that link up environmental considerations and socioeconomic development. As a consequence of the importance of the climate negotiations for several political areas, the negotiations in Bali in 2007 were also attended by finance, trade and international development ministers as well as their colleagues from the environment departments. There is fairly broad agreement that it is important to have sustainable development as a goal. However, there is a substantial difference between for example the USA and the least developed countries regarding what sustainable development actually entails in practical politics.

Market-based solutions

Global cost-effectiveness is one of the cornerstones of the Kyoto Protocol. One of the main lines in the ongoing negotiations is that established emissions goals linked to the trade in emissions credits must be the backbone of the international climate co-operation. The potential to link existing and planned markets for the trade in carbon dioxide is a topical issue for the future for international climate politics.

One risk that the EU and others are trying to avoid is what is known as carbon dioxide leakage. This occurs when emissions increase in one country because another country has introduced a tougher climate policy; for example if new restrictions in Sweden cause industries to move operations to countries with less ambitious legislation or a more generous allocation of emissions credits.

Another possible conflict between trade and climate goals relates to the handling of issues concerning technology transfer. Maintaining a technological lead is a fundamental strategy for many companies.

However, the developing countries have applied ever greater pressure to be granted significantly increased access to new and cleaner technology. According to the agenda from Bali, one precondition in the next climate agreement is that measures regarding the transfer of technology for mitigation from rich to poor countries must be reported, monitored and verified. According to some commentators, the market-based solutions also need to be supplemented with ethical principles in order to share the burdens of climate measures.

Principles for agreements

The global climate negotiations have been lined with conflicts between industrialised and developing countries. Although only industrialised countries have made quantitative commitments to reduce their emissions, this does not mean that developing countries have failed to take climate change very seriously and made other commitments within the Convention. In the years before the Climate Convention was agreed, several collaborative organisations among developing nations had highlighted the need for international co-operation in order to reduce emissions. The crucial point is how the burdens for reducing emissions should be distributed. This discussion can be summarised in four principles for distributing undertakings: a) common but differentiated responsibilities, b) the polluter pays principle, c) historical responsibility, and (d) per capita emissions. These four principles have had differing degrees of success in the negotiations.

The Climate Convention is based on the principle of *common but differentiated responsibilities*. This means that the nations of the world have a shared responsibility to "cooperate in a spirit of global partnership to conserve, protect and restore the health and integrity of the Earth's ecosystem" (Rio Declaration). However, this responsibility has different consequences for the countries as they have made different contributions to the global environmental load and have differing technical and financial resources. The principle is expressed for example in the Climate Convention's division into Annex I, Annex II and non-Annex I countries. However, it has proven difficult to put the global distribution of the burden into operation on the basis of a uniform criterion. The principle leaves scope for each country itself to define its capacity for liability and its contribution to global environmental destruction. If it had been decided that "the polluter pays" was to be the main principle, it would have been necessary to develop criteria to determine responsibility for the damage, and the time frames would apply from the time when the damage caused by pollution arises.

Prior to the Kyoto Protocol, Brazil proposed that *historical responsibility* should be the principle to determine the commitments to reduce greenhouse gas emissions. The starting point here is that the industrialised nations in the North have a historical responsibility to solve the problem, as it is their emissions that have caused most of it. By calculating the historical emissions from each country since the start of the industrial revolution, you arrive at key figures for the amount by which each country should reduce its emissions. For example, the most recent model developments within research on historical responsibility show that, using 1750 as a starting point, the USA is responsible for 23 per cent of the temperature increase according to the estimated impact of the three major greenhouse gases (carbon dioxide, methane and nitrous oxide) in 2005, while China is responsible for 10 per cent. However, if 1990 is used as the starting year, the figures are 18 per cent and 14 per cent respectively for the two countries. The starting year consequently plays a significant role if historical impact is included in the responsibility that countries have to achieve emissions reductions or to finance adaptation measures. Preliminary calculations show that Sweden's historical impact as a country lies between 0.2 per cent (starting year 1990) and 0.3 per cent (starting year 1750). If it were possible to weight emissions in relation to size of population, however, the impact per person in Sweden would rise considerably. It is not possible to determine by how much with absolute certainty, as there is considerable uncertainty about the historical population figures in many countries.

Brazil's proposal did not meet with much sympathy, as the Climate Convention's secretariat and many industrialised countries felt it was too complicated to calculate historical impact. The principle lives on, however. At the Bali meeting, the UN's Secretary-General Ban Ki-moon was one of those to speak about the importance of working on the basis of historical responsibility. Today, the proposals relate primarily to using the principle to allocate the size of commitments to pay for poor countries' adaptation to climate change.

A fourth principle that is increasingly being emphasised by major developing countries, such as India, is to work on the basis of emissions per person. If we use carbon dioxide, methane and nitrous oxide from the energy sector alone as a starting point, the USA's contribution (2005) was almost 23 tonnes of carbon dioxide equivalents per person per year, Sweden's was just over 7 tonnes, China's was 5.5 tonnes and India's barely 2 tonnes. The table on next page also shows (figures from 2000) that deforestation and land use plays a major role in some countries, such as Brazil, Mali and Tanzania. Carbon intensity targets represent an alternative method on which to base commitments. In his address to the United Nations in September 2009, for instance, Chinese president Hu Jintao announced his country's commitment to curb emissions per unit of Gross Domestic Product by a "notable margin" by 2020 compared to the 2005 level.

Emissions from some of the world's nations in tonnes of carbon dioxide equivalents per person per year (carbon dioxide, methane and nitrous oxide). (Source: World Resource Institute, The Climate Analysis Indicators Tool 6.0)

	Year 2000 (including forest and land use)	Year 2005 (excluding forest and land use)
Australia	26.3	26.6
USA	22.4	22.9
Russia	13.3	13.6
Brazil	13.2	5.4
EU (27)	10.1	10.2
Japan	10.1	10.2
South Africa	8.6	8.9
Sweden	7.8	7.3
China	3.7	5.5
Mali	3.4	0
Tanzania	2.4	0.1
India	1.5	1.7

After Copenhagen

Even though the principle of *common but differentiated responsibilities* still constitutes a cornerstone, the EU, the USA and others feel that at least the large economies in the South must also make commitments to reduce their emissions. The Bali meeting placed the USA as well as G-77 and China, which represent most of the developing countries, in square one in the negotiations regarding future commitments to reduce emissions of greenhouse gases. Considering they were previously not even on the field, this represents a major advance.

It is obvious that the USA needs to make far-reaching commitments, bearing in mind the country's extensive emissions of greenhouse gases. Many scientists and decision-maker maintain that the USA's participation is absolutely decisive for the next agreement. It is true that the Kyoto agreement was able to be brought home without the USA, but that was only a small first step. Substantial global reductions will be very difficult to achieve without the participation of the USA. There is also a risk that large developing economies such as China will be less inclined to adopt their own emissions reductions. An agreement without the involvement of the USA would also send uncertain signals to the market.

The Obama administration has clearly declared a higher level of ambition as regards climate policy, but Congress also has to give its approval in order for the

USA to be able to ratify an international agreement. The country will only enter into an international agreement when its leaders conclude that it can fulfil the commitments, as these will be legally binding in US legislation. Some commentators feel that the USA's participation in an international agreement is not decisive, however, but that considerable advances towards a reduced climate impact are nevertheless being made locally and in some of the country's States.

Even though the UN is the central arena for work on the climate, successes there are determined to a large extent by what happens outside of the Climate Convention. The current architecture is attempting to use market forces to steer us towards low carbon energy consumption. The extent of these reductions over the next few decades will depend on the market's reactions and priorities. Another decisive area is what is happening within the energy sector when it comes to development and access to low carbon energy types and increased efficiency.

If the results of the next agreement are weak, whether taken at Copenhagen in December 2009 or at subsequent negotiations, we will probably have a debate about the Climate Convention. In that case, there will probably be questions such as: Is the common UN track the right one? Should the market be allowed to solve the climate issue without political control? Should ethical principles be given greater emphasis? Is reduced consumption the fundamental solution? Is more stringent political control including prohibitions the correct route forward, rather than enticing carrots?

So far, however, the agenda from Bali, including increased commitment from the USA and China, is an indication that the Climate Convention has the potential to take an important step towards its goal over the next few years, despite the current economic crisis. Within the international policy, increasing attention is being paid to the fact that demands for new energy and transport solutions, which will lead to radically reduced global emissions of greenhouse gases, can also create new opportunities for economic efficiency and technical breakthroughs.

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We need a global price on carbon

Can the Kyoto Protocol's flexible mechanisms save the climate? No, not on their own, writes Lars Zetterberg. First, it is necessary for the world's leading nations to make concrete commitments regarding emissions reductions. After that, the flexible mechanisms can help us to achieve the goals at the lowest possible cost. They can be the tools that introduce a global carbon dioxide price, making the climate issue a matter for company boards of directors. There should not be any climate tax-free paradises where dirty industries can hide away.

Lars Zetterberg, IVL Swedish Environmental Research Institute.

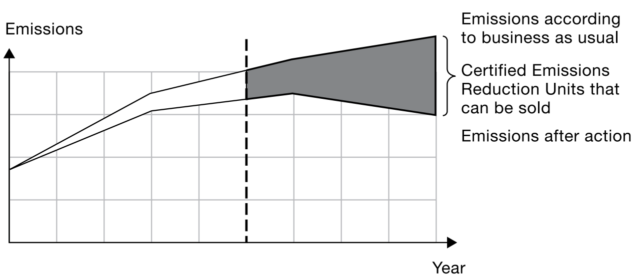
The Kyoto Protocol defines three flexible mechanisms: 1) Clean Development Mechanism, CDM, 2) Joint Implementation, JI, and 3) International Emissions Trading, IET. The flexible mechanisms mean that a country that, according to the Kyoto Protocol, has committed to reduce emissions can choose either to reduce its own emissions or to purchase reductions from another country. The purpose is to harvest cheap measures in developing countries and to help countries with reduction commitments to reduce their costs.

The Intergovernmental Panel on Climate Change (IPCC) emphasises that global emissions have to decrease by 2015–2020 at the latest in order to prevent serious climate change becoming a reality. After this, emissions must fall rapidly up until 2050. At the same time, the political work of drawing up a new international climate agreement is currently at an intensive stage. At the climate meeting in Copenhagen in December 2009, the world's countries need to agree on how emissions are to be reduced. With the experience we now have regarding the flexible mechanisms, many are questioning whether they can really help us to achieve the climate goals.

Flexible mechanisms – what do they entail?

The Clean Development Mechanism means that a country that has made commitments regarding emissions limits (such as Japan) can implement projects in countries that have not made commitments (such as India), leading to emissions reductions there. Let us assume that Japan invests in rationalisation measures in a coal-fired power station in India. Figure 1 shows how the emissions at the power station will develop over time. The upper curve shows how emissions would develop without the investment, whereas the lower curve shows how they are expected to develop after the action. After an approved inspection, Certified Emission Reduction Units (CER) are issued. CER can then be used by the investor country (Japan) to achieve part of its emissions commitment instead of reducing emissions in the investor country itself.

Figure 1. The principle of CDM.



The purpose of CDM is primarily to give countries that have made commitments the potential to reduce their costs by "harvesting" cheaper measures in developing countries in return for payment. Another aim of CDM is to increase developing countries' participation in the climate policy and to contribute towards sustainable development in these countries. The criticism that has been levelled at CDM usually focuses on the fact that it is bureaucratic, that the volumes are too small and that it is uncertain whether it will result in actual reductions. As a result, initiatives aimed at reforming the CDM mechanism are underway.

Joint Implementation is very similar to CDM, but applies between countries that have both made commitments regarding emissions restrictions according to the Kyoto Protocol (such as the EU, Norway, Japan and Russia). A country that has made commitments regarding emissions restrictions can, by investing in emissions-reducing projects in another country that has made commitments, obtain Emission Reduction Units (ERU).

International Emissions Trading makes it possible for parties with quantitative commitments according to the Protocol to purchase and sell emissions credits from and to each other. The Kyoto Protocol only mentions trading between countries. In the EU's emissions trading system, however, trading takes place between participating industries.

The EU's system for trading emissions credits

The EU's emissions trading system was launched in 2005. The purpose of the system is to contribute, in a cost-effective manner, towards achieving the EU's climate policy goal of reducing emissions by at least 20 per cent by 2020. The first trading period, 2005–2007, was a trial period. The trading system's second period (phase 2) coincides with the Kyoto Protocol's first commitment period (2008–2012).

The trading system currently only covers carbon dioxide, but during phase 3 (2013–2020) it will be extended to also include other greenhouse gases. The activities that are covered are the energy sector, production and processing of ferrous metals, the mineral industry and certain industrial facilities for the production of paper pulp, paper and cardboard. During phase 3, the system will be expanded to cover the aluminium industry, some areas of the chemicals industry, artificial fertiliser production and aviation, among others.

Emissions trading entails an authority determining in advance how many emissions credits are to be allocated and hence the maximum permitted emissions. In order to reduce total emissions, the authorities need to allocate fewer emissions credits than the emissions would otherwise have been. This creates a shortage of credits. The emissions credits are then allocated to the participants, either free via some allocation method or through sales or an auction. At the end of each year, the participants must then present exactly the same number of emissions credits as correspond to their emissions.

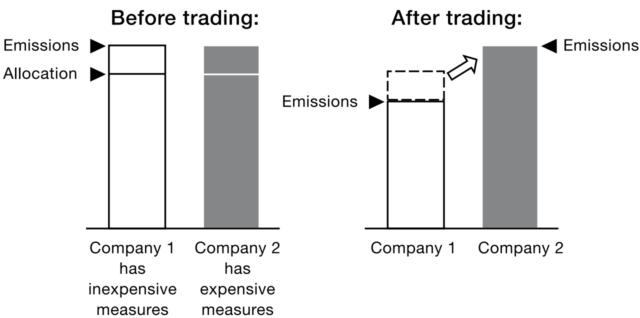


Figure 2. The principle of emissions trading. Companies that have high costs for achieving emissions reductions purchase emissions credits from companies that can implement inexpensive measures.

Figure 2 gives a schematic description of how the system can work. We are assuming that we have two companies, the white one with inexpensive emissions reductions and the grey one with expensive reductions. We are also assuming that the authority distributes emissions credits corresponding to 90 per cent of the company's needs. Without trading, both companies would need to reduce their emissions by 10 per cent. With trading, however, the white company can reduce its emissions further and sell its surplus to the grey company. The white company can sell the credits at a higher price than the reductions actually cost, whereas the grey company can purchase at a lower price than its own measures would have cost. Both companies benefit from this trade. The method is appreciated both by authorities and by industry. The authorities know in advance what the emissions will be, and the companies are given the flexibility either to reduce their own emissions or to purchase emissions credits. Economic theory states that if the market works perfectly, society's overall costs for achieving a given reduction target will be minimised.

Criticism leading to the system being changed

The EU's system is now in its second phase (2008–2012) and there have been many lessons learned since the outset. During the first phase, the system was criticised because there was a surplus of emissions credits at the end of the period, which led to a fall in the price of the credits. This surplus was probably due to an overly generous allocation. However, the surplus may also have been due in part to actual emissions reductions. The system was also criticised because of the distribution of free emissions credits. The criticism of the power companies was particularly strong, which raised the price of electricity despite the fact that they had received the emissions credits for free. This criticism was justified and has led to the electricity companies in future having to pay for their credits.

Prior to the third phase, which commences in 2013, the system will be revised in a number of important areas. To ensure that there is no surplus of emissions credits, the EU has already determined the total quantity of emissions credits for each year. The amount of allowances will decrease so that emissions in 2020 are 21 per cent lower than in 2005. Each member state will be allocated a certain number of emissions credits, which will then be distributed to that country's industry. The allocation will take place primarily through an auction of the credits. This means that the participating industries must purchase credits in order to cover their needs. In certain cases, some emissions credits will be distributed for free to industries that are subjected to significant international competition and that have high carbon dioxide-related costs. The allocation principles for this free allocation will be applied uniformly within the EU. However, the free allocation will only cover a proportion of the need, and will gradually be phased out by 2020.

The EU has set a price for carbon dioxide

From a global perspective, the reductions that are taking place within the EU's trading system are not large, it is true, yet they constitute an important international example of how market-based climate policy instruments can function on a large scale. This experiment has provided us with many lessons that are now being used in the international climate negotiations.

Perhaps the most important result of the EU system is that we have succeeded in creating a price for carbon dioxide across the whole of the EU. This price is something that all carbon dioxide-emitting companies have to take into consideration when making purchases and investments, as it can constitute a significant cost. From previously having been an issue for the environment departments, the climate issue has now become a financial issue for company boards. The price on carbon is now helping carbon-efficient production to become competitive, such as wind power and bioenergy.

Sector agreements – a step towards a global system

One of the most interesting proposals on a global scale is the creation of "sector agreements". This means that attempts are being made to capture all facilities in a particular sector within a single agreement, for example all electricity production in India. After having agreed on a reference level for emissions, the sector can reduce its emissions below that level and thereby receive emissions reduction units that can be sold internationally. There are several advantages: the reduction volumes can be significantly greater than from individual facilities and the method requires less administration. If sectors are selected that are active on the international market, this mechanism may also reduce distortions of competition between countries.

We can imagine a development whereby sector agreements are introduced in a series of countries and sectors, and are then linked together with emissions trading systems in the EU, the USA or other countries. Sector agreements are therefore viewed by some as a development from today's fragmented credit markets towards a future global carbon dioxide market that encompasses most countries and sectors.

What form should an effective global control system take?

The climate threat requires radical changes in all countries and sectors when it comes to the way we use energy, the way we produce goods, deal with our waste and manage our forests and agriculture. These changes will entail considerable costs for society, but these costs are still small compared to what the costs will be if we do nothing. So what form should an effective global carbon policy instrument take? Can the flexible mechanisms save the climate? No, not on their own. What we need are concrete commitments by the world's leading nations that can be translated into specific emissions reductions. Based on these reduction goals, I believe that the flexible mechanisms can help us to achieve these goals at a lower overall cost. The flexible mechanisms can be the tools that introduce a global price on carbon and thereby create incentives for emissions reductions worldwide.

In summary, I believe that a global control system should be based on the following points:

- *Greater reductions.* The level of emissions reductions must be set according to environmental requirements. This entails in the region of 80–90 per cent reductions in industrialised countries by 2050. In the longer run (2100), the goal must naturally be close to zero emissions.
- *Broad participation – a global price for carbon dioxide.* All leading economies in the world need to participate with concrete emissions reduction commitments. On the basis of agreed emissions levels, market-based controls, such as the flexible mechanisms, can create a global price for carbon dioxide and other greenhouse gases. A global price for carbon dioxide creates incentives for climate-efficient production. There must not be any climate

tax-free "paradises" where "dirty" industries can hide away. If we succeed with this, Swedish industry will not need to move away due to high carbon dioxide-related costs or be outcompeted by foreign industry that does not pay for its carbon dioxide emissions.

- *Long-term approach.* Industry is often prepared to reduce its emissions, but wants the rules to be long-term in nature and for the same conditions to apply to everyone. Their investment horizon can extend up to 10, 20 and sometimes 30 years into the future, depending on the sector in question. An international agreement therefore needs to be long-term and clear with regard to the principles that are to apply.
- *Justice.* Those of us who live in industrialised countries emit, and have emitted, significantly more greenhouse gases per capita than people in developing countries. We must therefore accept greater responsibility when it comes to reducing the climate threat. This means that we need to reduce our emissions by more than the developing countries, as well as contributing with financial support and technical development. The developing countries as a group are now responsible for more or less the same volume of emissions of greenhouse gases as the industrialised countries. As a result, they must also contribute with their

own commitments. This is particularly true of countries such as China and India, that have large-scale emissions and are experiencing strong economic development. Without their participation, we cannot expect to persuade the USA to sign up to a climate agreement.

- *Reduced deforestation.* Enormous amounts of carbon are bound in the Earth's forests. Almost a third of global emissions are due to deforestation. An international control system must create incentives to halt this deforestation. However, forests should also be viewed as a resource. Forests offer considerable opportunities to reduce emissions of carbon dioxide by supplying bioenergy, building materials and cellulose-based products, as well as by creating carbon sinks.

Lars Zetterberg is Head of the Climate Department at IVL Swedish Environmental Research Institute. He also works as a researcher in the fields of climate policy and energy systems, focusing in particular on emissions trading and the Kyoto Protocol's flexible mechanisms.

The EU's climate and energy policy – from rhetoric to practice

In the EU, the climate and energy policy is viewed as an instrument that should both resolve the climate threat and reduce the dependency on energy from unstable regions of the world. But how can the EU move from rhetoric to practical action? Society's conflicting aims are not visible in the rhetoric about the EU's climate and energy policy, argues Karin Bäckstrand. At present, the EU has neither the regulatory tools nor a democratic mandate to implement a major societal restructuring and transformations of energy systems, transport and consumption patterns for a carbon-efficient future. The power over energy supplies still lies in the hands of the member states.

Karin Bäckstrand, Department of Political Science, Lund University.

Energy security and climate security are two strategic goals for the EU that are becoming increasingly closely connected and that are at the top of the global political agenda. A range of problems that have previously been handled as separate political arenas have been linked together in recent years: a doubling of the price of oil since 2000, the melting of the glaciers by more than 30 per cent, the fluctuations on the global energy markets, instability in the Middle East, the increase in extreme weather phenomena, and the scientific world's assessments that the social costs of climate change could amount to more than 20 per cent of GNP. Dependence on oil and gas imports from politically unstable regions such as the Middle East is the basis for the EU's vulnerability.

The EU is arguably facing a climate policy and energy policy security dilemma. There is ample justification for the argument that the accelerating climate change, combined with the EU's energy vulnerability, jointly constitutes a crisis that is comparable with the oil crisis during the 1970s. Just as the oil crisis precipitated structural changes such as energy saving, energy rationalisation and the development of nuclear power, the climate threat and energy insecurity will demand a far-reaching transformation of the EU's policy. Climate and energy policies are embedded in security policy, where Europe's dual vulnerability is a prominent theme, both as a result of the EU's energy dependence on Russia as a regional energy superpower, as well as due to the threat to Europe's ecosystems, society and economy that climate change entails.

The EU is facing the challenge of unifying and creating synergies between the goals of increased growth, reduced external energy dependence and restricting the climate threat. The Union will probably barely achieve the goal of an 8 per cent reduction in carbon dioxide emissions by 2012 as stipulated by the Kyoto Protocol, and will have even less potential to reduce its external import dependence as regards energy. The Union has not yet developed the legal, political and institutional mechanisms to realise the long-term measures that are required to slow down climate change while at the same time guarantee secure energy supplies without being dependent on imported fossil fuels.

The energy and climate legislation is too weak

The EU strongly emphasises the harmony and synergies between the Union's climate and energy policies. Climate change and energy security in the EU are intimately linked, as the energy sector gives rise to 80 per cent of greenhouse gas emissions. A diversification of energy sources, a transition to renewable energy, energy efficiency and increased energy savings are contributing factors both towards limiting large-scale climate change as well as reducing the EU's dependency on oil and gas imports from Russia and the Middle East.

Central for the EU is the idea that the same battery of measures can slow down climate change and at the same time strengthen the Union's energy security. It is assumed that the Union's energy policy (which aims to reduce dependence on imported fossil fuels) and its climate policy (whose cornerstone is a transition to renewable energy systems) will mutually strengthen each other. In its current form, however, the EU's package of measures in the climate and energy policy area is not sufficiently powerful to live up to the vision of a carbon dioxide-free Union. In order effectively to tackle both climate change and the EU's vulnerability as regards energy, a structural conversion to an energy-efficient economy is required. The climate and energy issues affect many other policy areas, such as transport, security, tax policy and social issues, making the necessary co-ordination more difficult. In order to promote energy security and the restriction of the greenhouse effect in accordance with the Union's goals, much greater co-ordination of the EU's internal and external climate and energy policies is required, as well as extended powers for the Union to conduct energy policy.

The member states determine their energy policy
Within the EU, environmental issues are handled within the framework of the first pillar (i.e. the EC) with supranational competence (competence is another word for decision-making power). Formally, however, shared competence is prevalent in the fields of climate and the environment. This means that the legislative power in this area is divided between the member states and the Community, as opposed to trade, for example, where the Community has decision-making power.

The climate and energy policy is very much a cross-sectoral policy area that requires co-ordination between different sectors, such as transport, trade and agriculture. The EU's climate policy entails interesting experimentation with a series of new policy instruments, mechanisms and modes of governance. The EU's emissions trading represents the most developed regional carbon market in the world. All in all, the EU is a fascinating supranational experiment that handles the complex relations between globalisation, trade and the environment by developing comprehensive environmental and health protection legislation.

The competence as regards climate policy is divided between the Community and the member states, although power over energy policy lies primarily with the member states, which determine their own energy mix and have sovereignty over the energy sources. The fact that the member states have the freedom to formulate their energy policy and determine their energy supplies entails considerable legal limitations with regard to implementing a common energy policy, lessening fossil fuel dependence and strengthening the transition to renewable energy.

Ambitious EU goals for 2020 and 2050

The efforts within the EU aimed at creating an integrated climate and energy policy were intensified during 2007 and 2008. The Union's climate security can be framed as the two-degree target: limiting the increase in the world's average temperature to a maximum of two degrees compared to the pre-industrial period. The Union's energy security can be met by increased supply security through diversification of both the energy portfolio and energy suppliers, as well as developing an internal energy market that is subjected to competition and liberalisation.

In December 2008, the EU adopted a strengthened package of legislative measures in the climate and energy field. The Union aims to reduce emissions of greenhouse gases by 30 per cent by 2020 compared to 1990, provided other industrialised nations undertake to make comparable emissions reductions within the framework of a future climate agreement beyond 2012 replacing the Kyoto Protocol. Regardless of the level of ambition of the rich countries in a post-2012 climate agreement, the EU is committed to reduce greenhouse gases by 20 per cent by 2020. The long-term goal is for the EU to reduce emissions by 60–80 per cent by 2050 in accordance with the recommendations of the IPCC.

In a global perspective, the EU has agreed on relatively far-reaching goals for the reduction of greenhouse gas emissions for the second commitment period, i.e. after 2012. Given that the majority of the member states are already having difficulty meeting the modest (and from an environmental effectiveness perspective insufficient) Kyoto goals for the first commitment period, there is reason to view the ambitious goals beyond 2012 as aspirations rather than realistic and achievable goals. The credibility of the Union is at stake if these goals are not fulfilled.

The EU as a global climate leader

What is the compliance record for the EU with regard to the Kyoto Protocol? According to the Kyoto Protocol, the countries in the EU should reduce emissions of greenhouse gases by 8 per cent by 2010 compared to 1990 levels. The member states have agreed to implement this commitment jointly through the EU's "burden sharing" agreement, which specifies the contribution to be made by each member state. Overall, the states in the EU are having difficulty achieving their committments within the framework of the Kyoto Protocol's first commitment period. Only Sweden, Germany, France and the UK are expected to reduce their emissions in line with the mandatory emission requirements. Spain's emissions, on the other hand, have increased by 40 per cent between 1990 and 2003, i.e. much more than the permitted increase of 15 per cent according to the EU's distribution. However, the emissions trend indicates that the Union may be on the way to achieving its commitments for 2010 – provided the measures that have been decided on and planned really do result in reduced emissions.

Since the Bush administration rejected the Kyoto Protocol in 2001, the EU has taken on a role of global leader in the efforts to save the Protocol. With the hope of a new and more climate-friendly Obama administration, the EU is devoting considerable political efforts in order to ensure a global climate agreement to succeed the Kyoto Protocol in time for the UN's top-level climate summit in December 2009 in Copenhagen. This agreement will continue to build on the Kyoto Protocol's structure of binding emissions limits, as well as a fair framework that is based on countries participating according to their varying levels of responsibility and capabilities.

Conflicting aims and trade-offs not visible in the rhetoric

The EU's climate and energy policy is characterised by ambitious goals and visions of a new industrial revolution towards a carbon dioxide-free Union that can limit global climate change. In recent years, the Union has emphasised the importance of transforming Europe's climate and energy policy in order to meet intimately related challenges such as climate change, energy security and sustainable development in a more integrated and uniform manner. The EU has taken an international leadership role by setting far-reaching goals for the reduction of greenhouse gases by 2020 and 2050. The goals set out in the Kyoto Protocol are a first step, but from a climate benefit perspective they are not sufficient, according to scientific findings in the IPCC. The EU's climate and energy security will require a large-scale, long-term social transformation of energy and transport systems.

There are a number of trade-offs and conflicting aims with regard to climate and energy policies. The transport sector is one example. The freedom of movement in the EU entails increased transport, which together with energy production is the primary source of carbon dioxide emissions. There is a conflict between the EU's increased transport flows (a natural consequence of European integration) and measures to reduce the negative effects of climate change on society and ecosystems. In order to resolve this, a radical and far-reaching change of energy systems from fossil-fuels to renewable energy is required, as well as structural investments in transport systems. Such a transition to renewable energy systems in Europe may require far-reaching interventions in the day-to-day lives of citizens, such as raising the price of petrol, raised energy prices and restrictions to private car use.

This illustrates the limitations of democracy when it comes to meeting the global climate threat with radical measures. If the measures cannot be justified by the fact that there is an over-arching threat to the core of society, there will be no political acceptance of drastic changes to lifestyles and consumption patterns among society's interest groups and citizens. Fundamental trade-offs between economic growth, increased energy consumption and combating the climate threat cannot be seen in the EU's rhetoric, which emphasises win-win situations and synergies between climate change, energy security and sustainable development.

No mandate for social change

The necessity of a democratic mandate for implementing long-term restructuring of the core sectors of society, such as the energy systems, is a recurrent problem that entails a conflict of aims and key trade-offs. The climate threat represents a decision-making situation under considerable uncertainty and risk with regard to the future development of energy consumption, growth, population development and transport patterns. However, based on the current state of knowledge, we can argue that there are no inherent trade-offs or unsolvable conflicts of aims between the climate goal and energy consumption and growth in a longer time perspective. The Stern Review published in the UK in 2006, which attracted considerable attention, provides a cost estimate of the climate threat and describes with much-needed clarity that there is no conflict between limiting climate change and guaranteeing macroeconomic stability. The report states that the economic losses resulting from accelerating climate changes could, in the worst case scenario, be equivalent to 20 per cent of GNP if measures are not taken immediately to counter these changes.

Despite alarming scenarios from the Stern review and the IPCC, the reports have not generated a sense of crisis in public opinion, which is a precondition for a democratic mandate to implement a far-reaching change of society with regard to energy systems, consumption patterns, transport modes and lifestyles. Reports on the link between climate change and extreme weather phenomena have also failed to mobilise citizens sufficiently to demand or accept lifestyle changes or more radical reforms in core sectors of society. Examples of extreme weather events include recurrent storms and flooding in Northern Europe and prolonged drought in Southern Europe with associated problems such as reduced productivity within agriculture and forestry. The threat to human health, such as the increase of new infectious diseases, has also been linked to global climate change.

Disasters on a wartime scale justify mobilisation

As long as climate change is not perceived as an overarching threat to societal security among the EU's citizens, it is difficult to implement large-scale interventions in lifestyle and consumption patterns in democratic societies. Historically, war has been the primary justification for restrictions in democratic freedom and has facilitated radical interventions in the day-to-day lives of citizens, in the form of rationing and restricted freedom of movement. Political measures such as rationing transatlantic flights and limiting air travel would only be acceptable if the global climate changes in future were perceived as an over-arching social threat that requires mobilisation on all levels.

However, modern democracy has shown examples of resilience and the capacity to adapt in times of external crises. Democratic societies are quite simply the most effective political system for collective problem-solving in meeting large-scale threats, whether this relates to natural disasters, the threat of terrorism or global environmental risks. Arguably, if the worse case scenarios regarding the global climate are realised, there is a likelihood and evidence to suggest that the EU and its citizens will respond swiftly to the threat and mobilise to bring about a transformation of society.

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The EU's renewable energy dilemma

When Europe lays down goals for the increased use of biofuels, this affects people in low income countries, for example Indonesia, where oil palm plantations are expanding. Even though the EU's intention is for developing countries to have the opportunity to combat poverty by selling biofuels to Europe, it is not certain that it will work like this in practice. At present our European technical solutions are prioritised, without due consideration of the wider environmental and social implications in the countries that produce our biofuel, write Maria Osbeck and Neil Powell.

Maria Osbeck, Stockholm Environment Institute.

Neil Powell, Stockholm Environment Institute and Swedish University of Agricultural Sciences.

Climate change, in combination with rising oil prices, has lead to an increased focus on renewable energy sources, and biofuels are being presented as an alternative to fossil fuels. In conjunction with the EC directive on renewable energy, it is advocated that developing countries should receive assistance in utilising the opportunities for combating poverty that the growing markets for biofuel entail. By 2020 at the latest, 10 per cent of Europe's fuel for transport must comprise biofuel. The question is what consequences this will have in other parts of the world.

Using an example from Indonesia, we will illustrate some of the environmental and social impacts that are direct or indirect results of the EU's energy policy. We do not seek to adopt a position for or against biofuel, but rather to underline the importance of a holistic approach that gives consideration to the way biofuel production affects and interacts with food production, the environment and social conditions in various contexts.

Europe dependent on biofuel imports

In March 2007, the EU's heads of state and government agreed on an energy policy for Europe. This includes requirements for increased energy efficiency, reduced greenhouse gas emissions and increased use of renewable energy. The new energy policy aims to strengthen Europe's competitiveness, protect the environment and safeguard future energy reserves.

In order to achieve the goal of 10 per cent biofuels in the transport sector, large volumes of biofuel will be required, at least 17–18 million tonnes of oil equivalents by around 2010. The plan of action that the Commission has drawn up highlights the importance of increased trade in biofuels in order to satisfy the growing demand in Europe. The EU's own biofuel production in 2004 stood at around 2 million tonnes. This corresponds to 0.7 per cent of total fuel consumption, and is consequently far below the 5.75 per cent that is the goal for 2010. At an EU level, total investments in the production of biofuel are estimated to be in the region of 30 billion euro. The increased demand will partially be covered through imports. According to the EU's Joint Research Centre (JRC), imports of biofuel are expected to increase by 32–64 per cent in order for Europe to satisfy the goal of 10 per cent biofuel by 2020. In addition, the JRC states that indirect imports may increase to 80 per cent, depending on how much can be supplied within the EU through second generation biofuels for the production of biodiesel.

A wide-ranging debate for and against biofuel has resulted in the EU's Environmental Committee proposing a goal of 4 per cent biofuel in the transport sector by 2015 and a preliminary goal of 8–10 per cent by 2020. The final goal for 2020 will be determined in 2015, when the entire policy will be evaluated.

Carbon dioxide requirement with regard to ethanol production

Ethanol is the alternative fuel whose production volume is growing most quickly in relation to other raw materials for biofuels. The largest producers are Brazil (sugar cane) and the USA (maize). According to calculations that extend as far as 2010, total ethanol production worldwide will just about cover demand, which is expected to more or less double compared to today. The EU and the USA are net importers, while Brazil is the largest exporter.

The relatively high carbon dioxide emissions in conjunction with ethanol production have been discussed and analysed. The EC directive for renewable energy has determined that the production of biofuel must reduce carbon dioxide emissions by at least 35 per cent compared to fossil fuel. This has been questioned by critics, who feel that the EU should stipulate higher demands for reduced greenhouse gases from the production of biofuel. However, as ethanol production cannot achieve demands higher than 35 per cent, the EU has stuck to this figure.

Palm oil production increasing dramatically

Due to the low prices on the world market, European biofuel has had difficulty in competition with biofuel from developing countries. One raw material that is expanding rapidly is palm oil, above all from Indonesia, although also from countries such as Colombia and the Democratic Republic of Congo. Growing demand for biofuel and cooking oil for the food industry in Europe are strong driving forces. Palm oil has been presented as economically superior to other raw materials for the production of biodiesel based on the generation of high yields.

Imports of palm oil to Europe doubled during the period 2000–2006. According to the UN's agricultural body, the FAO, palm oil was primarily imported for the food industry to replace rapeseed oil, which is now increasingly being used to produce biodiesel. Malaysia and Indonesia are the world's largest producers of palm oil, being responsible for 90 per cent of the world's palm oil production. The growing global demand is expected to lead to a 50 per cent increase in production by 2017.

Environmental and social considerations in Indonesia

Indonesia is planning to increase the area covered by oil palm plantations from the current 7 million hectares to 24 million hectares. Almost 30 per cent of the intended land is on peatland that contains rich stores of carbon, which is incredibly problematic from a climate perspective. One study published in the journal *Science* which has attracted consideration attention, presents carbon dioxide emissions from various land types. The conversion of tropical forest into oil palm plantations for the production of diesel would, according to the report, result in emissions of 610 tonnes of carbon dioxide per hectare, which would take 86 years for the planned oil palm plantations to repay. The conversion of forest on peatland would result in 6,000 tonnes of carbon dioxide per hectare, which would take 840 years for the oil palm plantations to repay.

The social effects of increased exports of palm oil from Indonesia are linked to land rights, food production, safeguarded income as well as the rights of women and ethnic groups. In Indonesia, 30–40 per cent of the population are dependent on resources from the forest for their food and income. An impoverishment of local ecosystems will therefore impact on the local population's potential to utilise and live from the natural resources. Attempts to reduce negative effects on local populations have been made by supporting an expansion of small-scale palm oil production.

In Indonesia, around a third of palm oil production is small scale. Small-scale production includes land owners who themselves invest in the conversion of forest and land into oil palm plantations, contract growers who use their own land, as well as local farmers who are allocated shares of already established plantations. While land owners in the first group can choose for themselves which company they want to sell to, the other two groups are forced to sell to the contracting company. As the fruits from the oil palm must be processed rapidly after being harvested, this often ties the farmer to the nearest factory (unlike the Jatropha plant, for example, whose seeds can be stored and are therefore better suited to small-scale farming). Profit levels for the latter two groups are often minimal. Those who are not contract growers are dependent on machinery to convert forest or land into plantations; this often means that they are indebted to the large forest companies.

All in all, experiences from Indonesia show that small-scale palm oil production can generate income for landowners, but that the impact on ecosystems and local communities threatens the long-term sustainable development of small-scale palm oil production.

Increased conflicts

In the Indonesian part of Borneo, Kalimantan, close to the border with Malaysia, the Indonesian government is planning a large-scale expansion of oil palm plantations, which are expected to cover 5–8 million hectares. The UN's permanent forum for indigenous peoples has stated that 5 million people will consequently be threatened with compulsory relocation in western Kalimantan. A process of decentralisation within the administration has opened the door to greater influence from local government in the management of natural resources. Despite this, the system in Kalimantan is characterised by unclear procedures as regards decision-making and the division of responsibility. These ambiguities have enabled the commercial interests to exert a considerable influence in the decision-making processes regarding land rights, whereas local players and indigenous peoples have become even more marginalised. This has led to conflicts in conjunction with the expansion of oil palm plantations.

Conflicts between plantation owners and village residents have increased dramatically. According to the Consortium for Agrarian Reform in Indonesia, it was reported between 1998 and 2002 that 936 people had been arrested, 479 people had been tortured, 284 houses had been demolished, 134 people had been shot and 20 had been killed in conflicts relating to land ownership. Even though these incidents cannot be linked directly to oil palm plantations, it provides an insight into the complex institutional framework that regulates land ownership. In order to safeguard the sustainable production of palm oil, it is necessary for international laws and conventions to be followed, to ensure that forests with a high level of biodiversity are not converted into plantations, for commitments to be made regarding openness and the observation of local forms of government, and for cases that involve minority groups to be given priority.

Sustainability criteria miss the social impacts

Criticism of ethanol and biodiesel production has characterised the energy debate in Europe. In its action plan, the European Parliament observes that the choice of domestic energy crops is limited, and challenges the Commission to draw up new criteria for the import of raw materials used in the production of biofuel. They are seeking worldwide sustainability criteria for the production and use of biofuel. According to the Commission's proposal regarding sustainability criteria for biofuel, clear demands are stipulated as regards countering the negative impact on biodiversity.

There are no criteria at all for socially responsible development. The framework for the way the sustainability criteria are to be implemented and monitored is also unclear. One central issue relates to which land types are best suited to convert to plantations for biofuel production. The directive refers to "*marginalised land*", although which type of land this is referring to is not made clear. Experiences from Brazil and Indonesia show that areas that are often classified as "marginalised land" are already being utilised by the local population, for example for pasture or hunting.

Another area of uncertainty is how we should view the importing of palm oil to replace rapeseed oil in Europe's food industry. Palm oil that is imported for the food industry will not be covered by the sustainability criteria for biofuel. In addition, the criteria for land classification apply as from January 2008. In Indonesia, permits for oil palm plantations have been issued prior to January 2008, and 18 million hectares have already been prepared for future plantations.

Weak global policy

Europe's energy policy is facing a change of system, where a transformation from fossil fuels to bioenergy has proven to be necessary for energy security and in order to reduce carbon dioxide emissions. However, whether it is rational to use forest and agricultural resources to produce biofuel for the transport sector depends very much on the balance between different goals and the choice between national and global approaches. From a national perspective, the use of biofuels in the transport sector can produce a marked reduction in carbon dioxide emissions and dependence on imports. Viewed globally or regionally, however, this is hardly the best policy in relation to the global climate threat. The directive regarding renewable energy has unclear goals and aims. The most profitable biofuel systems at present are not the fairest or the most resource-efficient and climate-efficient in the long term. Technical solutions have formed the basis for the formulation of the directive, in the absence of social analysis as regards Europe's responsibility for food production, combating poverty and human rights around the world.

In these arguments, the relationship between process and results should be taken into consideration. Processes are complex, non-linear and self-organising, which means that a result is to a very great extent unique on the basis of the preceding process. The production chain for biofuels is distinguished by a complex reality. Technical innovations that have been developed on the basis of a linear approach between problems (dependence on fossil fuel) and results (energy security through renewable energy) have formed the basis for the formulation of the goals in the directive, which have now proven to lead to unpredictable results when it comes to the environment and social impact in low income countries. In other words, we can make a general comment about the process, while the results are characterised above all by being unique and tied to the particular location.

Indonesia in the starting blocks

The policy work that gave rise to the directive has, to a great extent, been driven by industry and politicians in Europe. The issue has now been raised again, as two of the EU's leading research and environmental institutions (JRC and EEA, European Environment Agency) have come out and publicly protested against the ten per cent goal in the transport sector. This illustrates the importance of a policy process that facilitates greater participation by various sectors and that respects the local populations' cultivation systems, supplies and legal systems. Since the decision was taken regarding the goal that 10 per cent of Europe's fuel should comprise biofuel by 2020 at the latest, and despite the uncertainties that currently characterise the biofuel issue in Europe, Indonesia has implemented measures to facilitate a dramatic increase in palm oil exports to Europe. While Europe is discussing and debating sustainability criteria, developing countries have already started making preparations for increased exports of bio raw materials to Europe.

Biofuel production's impact on and co-operation with food production, environmental and social conditions highlights the fact that the energy issue cannot be viewed as a linear process, where technical solutions will form the basis for a future sustainable energy supply. Measures aimed at reducing negative effects in low income countries that produce biofuel are necessary, which in turn demands a greater insight into the effects that Europe's biofuel policy can cause in low income countries.

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Neil Powell is a senior research fellow at SEI, where his work includes leading a Stockholm-based research group that is working on issues surrounding risks, livelihoods and vulnerability. He is also a senior lecturer at

the Swedish University of Agricultural Sciences. His research focuses on areas such as integrated and trans-boundary water management and social learning as a complementary governance approach.

Causes of climate change – what does social science say?

Why have these climate problems arisen in the first place? Social sciences give many, widely varying answers, writes Johan Hedrén. These differences are due in part to which factors are perceived as most important: ideas, economy, technology or politics. There is no scientific consensus on which social theorists are correct. Everyone has to form their own opinion. It is not sufficient to use modern media, which simplify matters far too much. If you want to understand complex issues, social theory has an important role to play.

Johan Hedrén, Department of Thematic Studies, Linköping University.

There is ever greater consensus that human activities are the primary cause of climate change, and as a result many questions are looming large. How is it possible that such a developed, modern society can place itself in such a difficult situation? Where are the most important driving forces? Who bears the responsibility? Is it a failure of global policy? Or is the policy at the mercy of the economic power structures? Are the problems based on the Western lifestyle? If so, why is this lifestyle the way it is?

There are naturally many more questions than this, affecting just about all activities in our society. In order to find the answers we have to look to the social theory that aims to understand and explain the big picture, and which is based on the very difficult question of how society as a whole works and develops. This form of social theory, often known as macro-theory, has to wrestle with incredibly complex situations. This challenge includes forming a well-founded understanding of how the various spheres in society work – politics, technology, economics, science, day-to-day life, media, etc. In addition, however, we need an analysis of how all these spheres interact and form a whole: society. It is therefore not particularly surprising that there are many, relatively varied interpretations of how everything is arranged and which are the most important driving forces for change. A great many social theories have therefore been developed over the years, and social science is both splintered and filled with conflicts.

What controls most?

The wide variety of explanations regarding historical developments can probably be largely explained by which factor or factors are perceived as being most important: ideas, technical development, economics, politics, etc. There is also much dispute as to whether it is actually worth attempting to understand society as a whole, whether this relates to individual nations or the global community.

This conflict is perhaps polarised most clearly between on the one side contemporary neo-Marxist theoreticians, such as Fredric Jameson and David Harvey, and on the other side liberal and conservative post-modernists. For the neo-Marxists, it is incredibly important at all times to develop and refine the theoretic understanding of society as a whole, and to do so in a thorough and systematic way. Without such an understanding, they believe, political work at all levels is a blind and vain pursuit. For the liberal and conservative post-modernists, on the other hand, the aim of trying to understand society as a whole and politics that rely on common sense and long-term planning appears to be both futile and dangerous. In between these positions are a range of theoreticians with a wide variety of opinions on the topic.

Interaction between a series of factors

Regardless of what attitude we take to the issue in question, i.e. the causes of social developments, it can be observed that the task of understanding and theoretically describing society has hardly become any easier over the years. One of the most radical changes occurred in 1989 with the fall of the Berlin Wall, when the relatively clear world order based on the Cold War between two superpowers was dissolved. Up until the break-up of the Eastern Bloc, the global political situation was at least somewhat comprehensible. It was also clear that this balance of power had a significant impact on social developments in general. Nowadays we have a situation instead where it appears increasingly reasonable to look for the causes of large-scale change in the interaction between a series of different factors, such as rapid technical developments, a rapid flow of alarming scientific findings and conclusions, a constantly increasing information flow, as well as economics and politics on a global scale that are difficult to interpret. However, the issue is handled in very different ways within different social science theories.

As to the issue of why we have ended up where we are, there are consequently a great many different answers. I will briefly describe and comment on some of the many theories that are on offer. I will look at various theories that have had a strong impact within social science and the arts that have focused particularly on environmental issues, as well as looking at the ideas of analysts who have considered the interpretation of the global contexts.

Urbanisation, population growth and growth thinking

One of the environmental history accounts to have received the most attention in recent years is J.R. McNeill's *Something New Under the Sun*. This provides a broad overview of the development of both nature and human society, and in the concluding chapters the author focuses on the issue of the driving forces behind the change. He is deeply sceptical of theories that highlight one or a few individual driving forces as being superior to others. Grand theories that offer a simple answer (entropy, capitalism, over-population, patriarchy, market failures, prosperity, poverty) are of little avail, he believes. Instead, the reader is offered what can almost be described as a collection of examples of how a great many factors at different times, in different places and in different social systems have, in various ways, resulted in the environment changing dramatically.

For example, McNeill writes about different energy regimes, i.e. combinations of a particular technology, particular energy sources, as well as laws and ideas. However, the environmental impact of these energy regimes is in turn dependent on other factors, such as how industrial production takes place, how far urbanisation has come, how large the population has grown, which economic system is prevalent, and so on. McNeill's historical writing often provides a picture of a very complex flow of events that is hard to grasp, and that is developing without any fundamental principle. Nevertheless, he cannot resist the temptation to highlight a few individual factors that are particularly important, although without substantiating or arguing why he has chosen these ones in particular. For example, he maintains that the most powerful "motors" that drove the change in the environment during the 20th century were urbanisation, population growth and population movements. He also highlights growth thinking as a type of overarching ideology.

Ecological modernisation – variation on an old theme

Despite a certain amount of uncertainty, McNeill believes that there are too many factors influencing developments to be captured in a general theory. Another contemporary theory is significantly more optimistic on this point, namely the theory of ecological modernisation, essentially formulated by the Dutch researchers Arthur Mol and Maarten Hajer. Their theory is one of those to have made by far the greatest impact in contemporary social-science environmental research.

The theory of ecological modernisation is linked primarily to a tradition of humanistic thought that investigates all aspects of *modernity*, or the *modern society*. This tradition often claims that a historically unique social form was created from the 17th century, originally in Europe. Within this social form, certain fundamental ideas are bound up with industrialisation, urbanisation and internationalisation. These ideas derive in large part from the philosophy of enlightenment: strong trust in human common sense, belief in progress and a conviction that scientific knowledge is superior to other knowledge and therefore should form the basis for development and reforms in all areas of society. It is believed that modern society's various characteristics are bound up in a kind of package, and that as a result the driving force for constant development and renewal, both spiritual and material, lies in this totality.

Those in power made ecology their own

In the theory of ecological modernisation, it is observed that the environmental problems originally came to be perceived as a crisis and a failure for the rapidly advancing modern society. In this respect, people use as their starting point the 1960s' and 1970s' debate literature, activism and opinion movements that often advocated an entirely different type of society. This frequently entailed striving for a small-scale approach, zero growth and decentralisation. Science was often criticised for being based on incorrect fundamental notions about the limits of knowledge and the basic nature of existence. Mol and Hajer, and many others, believe that those in power in society succeeded in defusing the criticism by making the ecological challenges a primary issue for social development. Ideas emerged about growth and environmental consideration being compatible, that increased prosperity and advances are achieved through specific investments in "green" technology and co-operation in concert between the state and industry.

The ecological challenges were consequently not only incorporated with, but rather the actual driving force in the modern project: ecological modernisation. That was the picture that was often conveyed, at least. In Sweden, as in many other countries, politicians argued that it was a matter of acquiring a world-leading position in the development of green technology, in order thereby to gain economic benefits and to preserve or strengthen the position in the international economic competition. Within this policy, the efforts to achieve an increased material standard have not been questioned, nor the level of energy consumption or the volume of travel and transport. To the extent the causes of climate change can be sought within these areas, the policy of ecological modernisation is an imaginary world well worthy of critical examination.

Global risk society

Another theoretician who has made a strong impact in social-science environmental research is Ulrich Beck. He also refers to the humanistic thought tradition regarding the modern society. He devotes considerable attention to the issues of globalisation and global relations. A large part of his analysis can be described within the framework of what he refers to as the theory of the global risk society. According to Beck, one of the most important driving forces for development and change over recent decades are the enormous global threats that have piled up since the Second World War. Beck is referring for example to environmental issues and in particular those that have a global distribution, such as the climate problems.

One particularly important event according to Beck was the accident in the nuclear reactor in Chernobyl in 1986. This disaster was both an enormous shock and a wake-up call that triggered new ways of relating to social developments. The new thing about the types of threat that Chernobyl represents, according to Beck, is that they target all social groups, that they are impossible to insure against and that the consequences of the disasters these can lead to are of a magnitude that is unique in historical terms; living conditions globally can be drastically impaired. This new situation, in Beck's opinion, means that everyone has an interest in changing procedures and organisations within both economics and politics. This cannot be expected to overthrow the modern project, although it can influence it to change the system in a number of central areas.

Modernisation with reflection

Beck believes that, in line with this, we can now observe a series of change tendencies that can be summarised with the term *reflexive modernisation*. Politics are becoming less centrally controlled, for example, and this is happening in such a way that scientific knowledge is more frequently supplemented with knowledge from people with solid experience of professional life or extensive knowledge about environments. This entails a more critical and testing attitude towards claims regarding definite knowledge on a general level. More policy is developed outside of the traditional political institutions by means of individuals, non-profit organisations, companies and networks working systematically and with a long-term approach on issues that are perceived as central. Within industry, too, there are good reasons to look for technology, production processes and products that have a minimal impact on the environment, as this can otherwise have an extremely negative impact on the brand.

For Beck, the traditional modern values regarding the importance of increased welfare, progress and development led by common sense and democratic politics consequently still appear to be central driving forces in social development. However, they are now being established within a new, different organisational framework and with a slightly altered, if you like more decentralised and democratic definition of rationality and progress.

Striving for ever greater profits

Another theoretician who is analysing global relations and also focusing on the handling of environmental issues is the neo-Marxist David Harvey. Like other neo-Marxists, he believes that development and history can only be understood if you investigate society as a whole, with all the complexity that this entails. One of the main reasons for this is the perception that the layers that tend to be designated as culture, economy, politics, social relations, etc., are basically strongly linked to and greatly influence each other. For this reason, it is incredibly important to understand the links between these layers.

Economic relations are perceived as particularly important when it comes to understanding social development. And in all societies, these are characterised by conflicts between the landed gentry and the poor. Much of what takes place in society, according to Harvey, is intended to manage these conflicts. Much of what happens is fundamentally about legitimising the differences or making them invisible. To achieve this purpose, ideology is created, i.e. a description of a reality that obscures these gulfs and makes them less controversial. For this reason, ideology is an important driving force both for preservation and for change, within the framework of an order characterised by major differences between the haves and the have nots.

The most important driving force within the prevailing economic system – capitalism – is an endeavour to achieve ever greater profits. Harvey and other neo-Marxists believe that this endeavour is unavoidable within this system, and that it has long formed the basis for economic development at a global level. Equally important, according to Harvey, is the predominant idea about what money is, as well as the incredibly important function that money has come to have in all parts of society. Through money, everything can now be exchanged for everything. Money, which is actually nothing more than a type of contract, thereby becomes the measure of everything. As a result, it becomes increasingly difficult to defend something because you believe that it has an inherent value.

The importance of reflexivity

It is obvious that this social-science theory provides a great many, extremely varied answers to the questions that were asked in the introduction. My examples have provided very brief and out-of-context insights into these extensive theories, with the aim of showing their diversity.

So who is right? Naturally, nobody can place themselves "above" this literature and make the final decision. Instead, everyone has to carefully reflect on the arguments and form their own opinion. I am convinced that it would be incredibly valuable if more people were to do precisely this. This would entail increased reflexivity, something that both Ulrich Beck and David Harvey would warmly welcome. To the extent Harvey is right, this would also counter the obscuring and distortion of the world generated by ideologies. Finally, there is reason to look at the tendency of the modern media to simplify, often beyond all recognition. Understanding complex contexts requires time and space, something there is an incredible shortage of in our extremely commercialised media world. Yet when it comes to the challenge of interpreting and understanding complex issues, social theory has an important role to play.

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Is the threat to the climate an opportunity for companies?

In order for Swedish companies to be competitive in countries such as India and China, they have to develop technology incorporating environmental performance that exceeds what is currently demanded by Swedish and European legislation, and they have to do this as soon as possible. The large growth countries in Asia will stipulate ever higher environmental demands due to their difficult environmental situation and rapidly growing middle class. Companies obviously have to abide by laws and regulations. But should they also accept voluntary responsibility for the climate and the environment? May they, can they, should they and do they? These questions are investigated by Pontus Cerin and Tommy Lundgren.

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The climate threat is stipulating demands for new technical solutions that produce lower emissions of greenhouse gases. This global development is creating several growth areas for environmental technology. Enormous population numbers in growth economies such as India and China are gradually changing into wealthy consumers. The new middle classes in these countries will place considerable demands regarding environmental infrastructure for the cleaning of air, water and sewage, as well as regarding energy technology. Material consumption will increase explosively. For example, global car production is expected to double by 2030. The vehicles of the future must be made lighter due to the shortage of resources and so that they do not consume as much fuel.

The EU is trying to reduce emissions of greenhouse gases within energy production and transport by encouraging the use of renewable fuels. As well as developing a common system that sets a ceiling for carbon dioxide emissions and underlying rules for emissions trading, the EU has established goals for the increased use of renewable electricity and biofuels. Energy rationalisation for buildings is also an area where environmental technology can reduce emissions of greenhouse gases.

The problems associated with man's contribution to the greenhouse effect will become even greater in future, in part because China is estimated to have sufficient coal reserves to last another 200 years. Bearing in mind the country's rapid development of coal-fired power stations, as well as the development of coal gasification for electricity production and coal liquefaction for internal combustion engines in vehicles, there will be an extensive requirement for environmental technology to reduce emissions of carbon dioxide.

In order for people in villages without an environmental infrastructure such as water and sewage treatment to gain access to services, communities must have access to energy. For many villages in areas such as Bangladesh and Africa, however, the costs are too high for them to be connected to existing energy systems. It is therefore important to create local, independent energy production that is based on renewable energy such as solar cells, wind and bioenergy. A strongly growing market in the future is predicted here, as well as an opportunity for companies that specialise in new and environmentally friendly technology.

Increasingly stringent demands from growth economies

In order to develop new technology for the sake of the climate, it is important to have a very good picture of the outside world. This applies not only to enterprises, but also to legislators, particularly in a small, open economy such as Sweden's. In order for Swedish companies to be competitive in the large and rapidly growing economies in future, it is necessary for the companies, within the near future, to develop environmental performance that exceeds what is demanded by current Swedish and European legislation, since the environmental problems will be much more serious on these growth markets.

The Chinese chemicals legislation already goes further than the legislation of the European Union in certain areas. Stringent environmental requirements and standards can acts as barriers to Western products. This can be viewed as a trade barrier, and US authorities have reacted against some Indian and Chinese environmental requirements. Companies in these rapidly growing super-economies will also stand up for increasingly far-reaching demands for environmental performance. The world's largest mobile operator, China Mobile, is already stipulating stringent energy rationalisation demands for a 40 per cent reduction in energy consumption per call by

2010 compared to 2005. This is applying pressure on both domestic and foreign mobile system suppliers, such as the Swedish based Ericsson.

Technology-neutral and long-term regulations

The US environmental legislation tradition has been strongly criticised by Harvard professor Michael E. Porter, who considers that lawyers have far too prominent a role and often insufficient knowledge of industry. He believes that the legislation in Germany and the Scandinavian countries promotes innovation, while still incorporating strict goals for what is to be achieved. Porter also points out that the desire for collaboration between companies and legislators in these countries frequently results in the environmental improvements coming further than in the USA, and also at a lower cost for the companies. This is because the regulations are better adapted to the companies' investment cycles.

According to Porter, the legislation should focus on results and not tie the regulations to a particular technology. An example of results-oriented regulations are those that the European Parliament adopted in December 2008, entailing stringent emissions requirements for vehicles that are sold within the European Union. Per car producer: By 2012, cars that are registered must have average maximum emissions of 130 grams of carbon dioxide per kilometre; this is a reduction of almost 20 per cent compared to vehicles that are newly registered within the Union at present. By 2015, all newly registered vehicles per car producer must achieve this goal, and by 2020 average carbon dioxide emissions must have been cut to 95 grams per kilometre. This provides the car manufacturers with long-term goals for technical development that they can take into consideration when designing new models and engines. In other words, the EU is currently creating a competition between engineers to achieve a far-reaching results target!

According to Porter, regulations should also employ phasing in periods that give consideration to companies' investment cycles, making it possible for companies to implement major changes when they are investing in new technology. The legislation should also be strict, without various exceptions for certain parties, and should take some precedence over legislation in other countries in order to provide domestic companies with a competitive advantage, enabling them to adapt earlier than foreign competitors. It is very important for the rules that are developed to be long-term and predictable for the parties involved – and adapted to industrial cycles rather than being changed after the next political election.

The way companies are viewed often relates to the way they deal with future legislation that is more or less taken for granted. Professor Peter Dobers at Mälardalen University describes, however, how companies and other players are already acting in the legislation creation process in order to gain advantages for their own technology. Successful parties then have the opportunity to develop regulations that favour their own technical solution and exclude the technologies of their competitors.

Volvo's strategies different in California and Sweden

When California wanted to draw up catalytic converter legislation to clean up vehicle exhaust emissions in 1976, the three major car manufacturers from Detroit opposed these attempts and claimed that such technology would be extremely expensive. Volvo on the other hand, which was a small niche player on the Californian market with premium car ambitions, saw the opportunity to extend its distinctive character and social responsibility by not only offering safe cars, but also environmentally sound cars for affluent, environmentally aware consumers. Volvo, in collaboration with the German company Bosch, showed American legislators that it was perfectly possible to produce cars with catalytic exhaust purification on an industrial scale. For Volvo, this additional production cost was not a problem, as it was able to generate a higher luxury feel for the brand, a willingness to pay more and to shift the costs for the catalytic converter to the end consumer with interest.

A decade later in Sweden, on the other hand, Volvo was the dominant player with a fifth of the country's total car sales, and was unable to pass on additional production costs for catalytic converters to the large domestic customer group. In Sweden, Volvo was competing on the mass segment, where prices are generally lower and only a small proportion of the clientele are made up of consumers who are prepared to pay more for a good environment. In Sweden, the dominant car manufacturers succeeded for a long time in stalling the introduction of regulations requiring catalytic converters. When catalytic converter legislation became unavoidable in Sweden in 1989 – more than ten years after Volvo's conflicting actions in California – Volvo succeeded in creating transitional regulations for a couple of years, whereby the Swedish State gave a few thousand SEK in tax relief to each car purchaser who bought a vehicle with a catalytic converter.

In other words, a company may very well have completely different strategies for its environmental work and its collaboration with authorities depending on its market position and the potential that the company has to pass on costs for production and technology development to its customers. This means that the environmental strategy does not need to be the same for the whole company, but can depend on what is most beneficial for the company's generation of profits, market by market.

Voluntary social responsibility – is it sustainable?

Part of the climate and environmental discussion has been devoted to what companies voluntarily can do (and actually do) to contribute to sustainable development. According to conventional economic theory, companies maximise their profits during technical and other restrictions. Without incentives such as taxes or subsidies (sticks and carrots), there is a risk of companies releasing more than what is socio-economically optimal. This traditional approach to enterprise must be revised, as we are now seeing many examples of companies that are doing more in the environmental field as well as other areas than they are required to do by law. This phenomenon is known as *Corporate Social Responsibility (CSR)*. We are now going to discuss this phenomenon from an economic perspective.

What is the role of companies when it comes to the environment? We can all agree that companies have to follow the law. But in addition to regulations and ordinances, do companies have any further responsibility to set aside resources intended for profit generation and instead transfer them to environmental work? What attitude should we take to companies voluntarily "sacrificing" profit to the benefit of the environment? Much of what is written in this area is both confused and confusing. Yet there are four main issues we should ask ourselves when it comes to socially responsible companies: *may they, can they, should they* and *do they?* We will now look at these issues in order.

May they?

Is it permitted to use the company's resources for environmental work that goes beyond what is required by laws and regulations? The answer may at first appear obvious. In those cases where voluntary environmental work has a positive impact on profit or is profit-neutral, there is of course no problem; the company is maximising its profits (*strategic CSR*). This might include generating goodwill that attracts customers or increases customer loyalty. But in those cases where the company management "sacrifices" profit (*altruistic CSR*), the answer is less obvious. This means that the people who own the company (the shareholders) are "cheated" of their rightful compensation as risk-taking investors, and some would even call it theft.

In the USA, there are examples of shareholders who have taken company managements to court for exceeding their authority, although this has never led to any convictions. It has been difficult to prove that specific voluntary environmental measures have directly impeded profits. According to Einer Elhauge, a professor at Harvard Law School, company managers can and should manage their company according to the principle of “business considerations”, and this provides them with relatively broad room to manoeuvre when it comes to using the company’s resources. This means that CSR can only be considered unlawful in extreme cases.

Can they?

Is it a sustainable strategy for a company to sacrifice profit for the environment, or will competition on the market lead to such companies disappearing in the long run? Paul Portney, Dean of Eller College of Management, University of Arizona, believes that companies that have some form of monopoly situation or that produce products for well-defined niche markets (very specific products such as new, environmentally friendly technology, for example) can pass on costs for CSR to their customers more easily.

However, for the majority of companies that trade in similar (homogeneous) products on markets that are subject to competition, it can be very difficult to pass costs for voluntary environmental work on to their customers without negatively affecting their competitiveness. Such companies then have to absorb these costs themselves, resulting in lower profits, lower share dividends and lower remuneration for the company management. This means that, on competitive markets, CSR is most probably not sustainable from the company's perspective.

There can also be instances of CSR that are justified by wanting to anticipate future legislation. By demonstrating "good behaviour", costly rules can be avoided. This phenomenon is studied in the research literature with the aid of models in which companies and regulators play a strategic game.

Should they?

This takes us to the next question. Even if companies are in a position where for some reason they find it beneficial to be socially responsible, the question is: *should they?* Is it socio-economically worthwhile? Does such behaviour lead to the effective use of our shared resources? Or to be more specific, under which circumstances does CSR increase welfare? According to Professor Portney, it is most probable that this takes place when companies are pursuing strategic CSR, i.e. when it is worthwhile from a business economics perspective (*good business*). The alternative, altruistic CSR, is obviously more costly as it does not create any added value among customers, i.e. people are not prepared to pay a higher price (or buy more at the same price) for greener products, for example. From a welfare perspective, it can be said that companies should invest in those projects that generate the highest possible social welfare. This means that CSR is desirable if overall welfare is higher with CSR than if it were not permitted.

The question then is whether companies should regulate themselves voluntarily, or whether a central planning body is better for this task. There is reason to suspect that many companies are not always able to make investments that would maximise socioeconomic welfare. This is because a company's CSR decisions are determined by a range of factors, many of which are not related to social benefit. Individual companies probably possess good knowledge about the private economic costs of CSR, although the benefits are more difficult to estimate. This asymmetry can result in the company choosing an ineffective level for its environmental protection, i.e. too much or too little.

However, there are also cases where the company is better informed than a regulator. This relates for example to information about the company's emissions activities, as well as the costs for monitoring these. Such information can result in a company being able to implement better informed and more optimal decisions than a central regulator. Furthermore, CSR investments can increase welfare in those cases where the level of a centrally determined environmental regulation has been set "too low", i.e. if the social benefit exceeds the social cost. There can also be welfare-improving CSR, which is targeted at alleviating environmental problems that are wholly or partially unregulated, but that are of considerable human, scientific or political importance, such as climate change.

Do they?

Can we see companies voluntarily and successfully going further than the legal requirements and investing in CSR? There is no lack of examples of voluntary commitments. One such example relates to the various types of environmental agreement that are entered into between companies and governments, trade organisations or other social groups. Other examples include various types of certification, for example for forest products, or other environmental labelling of consumer goods, such as the Swan or "Good Environmental Choice". Entering into these agreements is completely voluntary, and can only be explained by the companies considering the net benefit to be positive, i.e. the cost of changing the product is less than the income that the change generates.

Forest Reinhardt from the Harvard Business School has recently analysed a large number of studies and found that in most cases it is not worthwhile being voluntarily "greener" than the level that has been determined by law. In certain cases, however, CSR can be profitable, namely when the company can increase its customers' willingness to pay, reduce its costs, reduce risks or anticipate costly future regulation. Reinhardt recognises that there are companies that have utilised CSR very successfully in their business models, such as Patagonia and DuPont, although on the whole it is difficult to find support for the idea that CSR generally entails business opportunities and increased profitability.

Corporate climate for environmental engineering and social responsibility

Legislators who are developing regulations within the field of environmental engineering should understand industry and consider industry's investment cycles. In order for the best possible technology to be developed, legislators should focus on environmental performance and not on which technical solutions that are to be used. It is important to create a climate that enables technical development and companies to incorporate the major cleaning, energy and climate requirements of the future. And it is important to have a good picture of the needs that exist in the large growth economies.

So what attitude should we have to socially responsible companies? Should companies engage in CSR over and above statutory environmental goals? Is it sustainable to do so from a business economics and socioeconomic perspective? If the company does not operate in a monopoly situation or on a niche market, the answer is probably no. Should companies sacrifice profit for the environment when the alternative is effective environmental policy carried out by a central regulator? No, in all likelihood not.

It is tempting to view the growing interest in CSR as a new ethical approach or increasing commitment to sustainable development. However, CSR is also consistent with another explanation. Companies and individuals are changing their behaviour in line with altered prices and higher income, just as they have always done. It is reasonable to assume that preferences ("tastes") have also changed. There are empirical studies that show that the richer we become, the more we care about the environment. The CSR that exists can largely be explained as a conventional economic adaptation to new market conditions.

CSR can also raise welfare with a positive net benefit when it is targeted at those environmental problems that are wholly or partially unregulated. Increasing emissions of greenhouse gases and the warming of the Earth's climate are examples of such an environmental problem.

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Climate and business climate – collision between two worlds

The global climate issue and the global business climate have major similarities, but also major differences. The climate issue is collective in nature, whereas the business world is driven by self-interest and ideas of growth, writes Johan Sandström. Growth in the economy means “growth” in climate impact. The challenge is to find solutions that benefit both the climate and companies. In the absence of global institutions that have the power to persuade global companies to accept more responsibility for the climate issue, clear signals are required from strong global citizens.

Johan Sandström, Swedish Business School, Örebro University.

Global warming is diffuse and abstract, full of uncertainty, filled with risk and long-term in nature (the things I do now won't be noticed for some time). It is also a matter of solidarity with other people, both those alive now and future generations, and of the common good. The climate issue is less a question about me and my life, although we as individuals can make a difference. We can act more responsibly.

Doing business on a global market, thinking like the manager of a global company, means prioritising narrow calculations (is it profitable or not?), competition and constant improvements and transfers, growth, short-sightedness and egoism (what do I, our business partners, owners and investors actually earn from this?). It is mostly about me and a select few within the corporate sphere.

In a fairy-tale world

I would like to write a success story about global companies and global warming. About how innovative, global companies with plentiful resources are leading the battle against increasing warming of the Earth's climate. This would be a story that provides solace to those who believe that it is too late, that inspires those who are still wondering, and that showers words of praise over those who have already taken action. But unless something more radical is done, this story will remain something from a fairy-tale world.

The reality, as I see it, shows that companies and the global business climate we are living in basically find it very difficult to manage their relationship with global warming. Just take a company like Volvo Cars. The company conducts extensive environmental work, yet their products are fundamentally destructive to the environment when they are being produced, distributed and consumed. What does it actually mean when, after having "saved people from car accidents for 80 years", they state in their advertising campaign that they "have another challenge", i.e. saving the planet?

Global companies dictate conditions

The former Chief Economist of the World Bank (and winner of the Nobel Prize in Economics), Joseph Stiglitz, believes that the difficulty in solving the issue of global warming is largely due to an overly prevalent and one-sided economic approach. In his opinion, today's globalisation is driven with economic business overtones, where global companies and market-liberal politicians jointly dictate the conditions.

I share this overall view. We are witnessing globalisation whose advances are unilaterally related to increasing production and consumption of items, and hence to increasing environmental destruction. On the whole, a growing global economy that is dependent on an increasing stream of new items means an increasing environmental impact. If one grows, so does the other. Volvo Cars wants to sell more, not less, and even their "environmental cars" fundamentally soil the environment rather than making the environment more "sustainable".

The myth of success

Of course, there are now those who want to convince us that this is not the case. They say that economic growth (i.e. greater turnover of resources in society, in terms of money) and a prosperous planet obviously go hand in hand, and that more competition, freer markets and trade lead to reduced environmental impact. They believe that a growing economy leads to new, less environmentally burdensome technical innovations and a higher standard of living, which they also believe are required in order for you and I to care about the environment.

According to this argument, we should consequently consume our way out of the problem, for example by buying a green car instead of a fossil car and organic milk instead of ordinary milk. This does not question the importance of good turnover on the market. On the contrary – we can carry on shopping. This in turn provides more prosperity for all, and also results in the items we purchase in the long run becoming more "environmentally friendly". A win/win situation, quite simply. According to this argument, the following link also exists: The richer we become, the better the environment becomes.

The starting point for this success story is efficiency, and a great deal counts on this. There is much talk of how much carbon dioxide emissions per unit (kilometres, tonnes, cubic metres) are reducing in certain cases. The graph that is not readily included in these contexts is the one showing that emissions on the whole are increasing dramatically. If we include that graph, the nature of the story changes, from a success story to a success myth.

When the wallet swells

It is generally the case that the richer we become, the more we burden the environment with our increasing production and consumption of goods. However, this is not often sold by the progress optimists, i.e. the ones who are doing business (such as company managers) and those who are trying to understand business (such as economists). They do not talk about what normally happens when people have a little more in their wallets and can increase the number of square metres in which they live (from a one-room to a two-room property, to three, to four, to a house and a summer cottage), when an (extra) overseas holiday becomes possible, when they can afford to use the car a little more often, when they acquire a new mobile phone, an espresso machine, a new iPod, slightly more modern clothes, and so on.

It is also easy to grow accustomed to a slightly higher material standard of living. In Sweden we buy more than 3 million new mobile phones and 300,000 new cars each year, and we are the world leaders when it comes to the highest number of square metres of shopping centre per inhabitant. World leaders! The last two items, cars and shopping centres, often go together, by the way. This is because walking or cycling to a shopping centre can be difficult these days. They are usually designed for motorists, not for pedestrians or cyclists. It is also ingenious, when the car gives such a superior economic footprint compared to taking a bicycle. If we take the car, we see an increase in turnover in our wallet, in various companies (the oil company, the petrol station, the workshop, the insurance company, perhaps at Volvo) and in society as a whole (GNP includes all economic activities that create value, even those that harm the environment). If we believe that a growing economy produces a better environment, then we should take the car. However, using the car instead of the bicycle means, without paraphrasing, that we are fuelling global warming.

Collective requirements versus personal benefit

Growth in the economy still means "growth" in climate impact. It is therefore difficult to get around the need for us to rethink the relationship between economy and ecology, a notion that has occupied philosophers, social scientists, activists, politicians and even economists for a long time. However, these players have not met with much sympathy. Economic globalisation appears instead to be gaining ground over more sustainable development. The fact that more and more people are thinking along economic lines has become almost taken for granted.

Nowadays, few politicians and company managers would gain much support for saying that we need a smaller economy, lower growth, to produce fewer products and to consume less. Even though this is to some extent what is required, it is, for many, more or less like saying that "we ought to all become a little poorer". This sounds almost as stupid as saying that the use of cars produces a better environment.

In other words, we have a collision between two worlds, fundamentally between the collective requirements of the climate issue and the personal benefit of the business world. These are two different concepts, two different ways of meeting the world, and tensions therefore often arise. Solutions that benefit both are a challenge that we should not underestimate. It is the scope of this challenge that causes me to feel no more than cautiously optimistic, yet it is also the challenge itself that makes it so rewarding to work on these issues. And of course it is possible to choose to focus on interesting examples out there that question my simple classification. Even though the broad strokes I have painted so far are applicable to me, the reality is normally a little more complex, muddled, grey and occasionally pink. Perhaps there is sufficient material out there that the seed for a success story can be sown and which can then perhaps develop into something bigger (good growth, in other words).

Lack of powerful institutions

To provide a little help along the way, there are also clear similarities between global warming and doing business in a global business climate. The warming of the climate is global, knows no boundaries and requires enormous resources. Today's business climate is characterised more than ever by global companies with enormous resources and that often know no boundaries. In some way, as the UN's former Secretary-General Kofi Annan also realised, we have much to gain by getting the global companies to take an interest in the climate issue "world". For example, if a large, global company decides really to focus on something (to refrain from drilling for oil in a conflict zone, to develop the next generation of green car, or to encourage its customers not to consume as much), there are few organisations that can match the mobilisation of resources that would then commence.

However, there is currently a lack of global and occasionally even national institutions that are able forcibly to persuade global companies to accept more responsibility for reducing global warming. Many companies are in front of democratic organisations when it comes to globalisation, and the companies naturally ensure that their economic interests are provided for in this development. The companies benefit from differences between nations that themselves are relatively firmly anchored in national legislation and national institutions. We are now also seeing companies jump from one export zone to another, where politicians are also important accessories, marketing "their" regions and countries as those with the least demanding regulation.

The UN focused on self-regulation, on companies voluntarily following national and international environmental legislation, anti-corruption laws, workers' rights, human rights, and so on. This is one way of generating interest among companies. However, neither the UN nor any other political institution has the potential to implement a legally sanctioned system of punishments that has an effect when the companies do not follow these guidelines. In the business climate in which these companies live, we should perhaps not expect them to want to accept greater environmental and social responsibility.

Strong consumers and citizens

Other methods of attracting interest are therefore required, for example in the pressure that you can bring to bear in your roles as both a consumer and a citizen. How do you act when you go into a shop? What do you see, what do you choose, what do you ask? What do your friends do? Where do you think that "your" politicians on a local, national and European level stand when it comes to the relationship between economy and ecology?

There are currently a great many examples of small amounts of pressure resulting in large changes. There is the example of a number of Western companies that have gone into regions where fundamental rights are not satisfied and that, after pressure from at home, have "voluntarily" shouldered a role that the country's public sector actually ought to have played. These companies have invested resources in organising schools, healthcare and nursing for their employees and families, for example, as well as investing in some environmental technology on site. This is not necessarily exclusively positive, of course, although they are at any rate initiatives that can be developed and that allow us to discuss what happens when these worlds collide.

Companies need your help and support in order to act more responsibly. They do not only need to be guided by strong institutions that regulate their behaviour on a global market, but also require clear signals from strong global citizens.

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Glossary

Aerosols
Small airborne particles.

Albedo
That part of the solar radiation that is reflected off a surface. Fresh snow and new ice have a high albedo. Open sea and land covered with vegetation have a low albedo.

Anthropogenic
Due to human activity or created by humans.

Atmosphere
The thin layer of gases that exists around the Earth.

Biosphere
All the Earth's ecosystems, organisms and degraded organic material – in the atmosphere, on land and in the sea.

Carbon cycle
The flow of carbon in various forms (such as carbon dioxide) through the atmosphere, the sea, the terrestrial biosphere and the Earth's crust.

Carbon dioxide equivalents
Greenhouse gases such as carbon dioxide, methane, nitrous oxide and fluorinated gases have different radiative forcing effect. The carbon dioxide equivalent of another greenhouse gas is the concentration or emission of carbon dioxide that produces the same effect as the other greenhouse gas in question.

Climate model
A computer model of the climate system, based on the physical, chemical and biological properties of the system's various components, their processes and their interaction, including feedbacks.

Climate sensitivity
The long-term, equilibrium increase in the Earth's average temperature for a doubling of the carbon dioxide concentration in the atmosphere.

Condensation nucleus
A small airborne particle that serves as an initial point for the condensation of water vapour into water. The resulting small droplets can then develop and form clouds.

Deforestation
Conversion of forest areas to other land use.

Feedback
An interaction mechanism between different processes is a feedback when some initial process triggers changes in another process, which in turn affects the first process. A positive feedback strengthens the initiating process, whereas a negative feedback weakens it.

Glacier
Land ice that moves slowly down a valley, for example. The ice runs down to the sea or melts at a lower altitude, and is maintained through snowfall at higher altitudes.

North Atlantic Oscillation (NAO)
Consists of opposing variations of barometric pressure near Iceland and near the Azores. It therefore corresponds to fluctuations in the strength of the main westerly winds across the Atlantic into Europe, and thus to fluctuations in the embedded cyclones with their associated frontal systems.

Palaeoclimates
Climate during periods before there were measuring instruments, both historical and geological eras. There is only proxy data for these (see below).

Permafrost
Frozen ground where the soil temperature is lower than 0 degrees Celsius for at least two years.

Photosynthesis
The process whereby plants, algae and certain bacteria, with the aid of solar energy, produce sugar out of carbon dioxide and water, with oxygen as a residual product.

Proxy data
Data about the climate in older times that is obtained by investigating e.g. ice cores or tree rings, i.e. various climate-related properties that can be interpreted to obtain estimates of past climate data.

Radiation balance
The balance between incoming radiation from the sun to the Earth and outgoing thermal radiation from the Earth into space.

Radiative forcing
The change in the Earth's radiation balance (in watts per square metre) due to factors that affect the climate system, such as carbon dioxide concentration in the atmosphere or solar variability.

Resilience
The ability of ecological and social systems to withstand disruptions without losing structure and function; the ability to adapt to stress and change.

Respiration
The oxygen-demanding process in which organisms convert organic substances into carbon dioxide, while emitting energy.

Scenario
A plausible and often simplified description of how the future may develop based on internally consistent assumptions about driving forces and processes.

Sea ice
All ice at sea that originates from the freezing of seawater.

Sink
A process or mechanism that removes a greenhouse gas or aerosol particles from the atmosphere. Photosynthesis is an example of a carbon sink, when it leads to a permanent build-up of biomass or soil carbon.

Stratosphere
The part of the atmosphere located at an altitude of between around 10 and 50 kilometres (above the troposphere).

Threshold
A level at which there is a rapid change to a process or response in a system (ecological, economic or other system). When a threshold is passed, a continued influence has a significantly different effect on the process than before. A system that tips over at a threshold (passes a tipping point) can change drastically.

Tipping point
See Threshold!

Troposphere
The lower parts of the atmosphere (below the stratosphere) from the Earth's surface to an altitude of approximately 10 kilometres.

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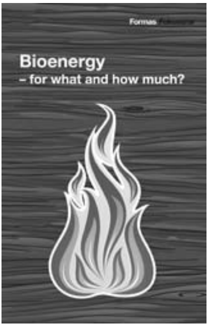
IN ENGLISH



Bioenergy – for what and how much?

How long will bioenergy last for the energy systems of the future? How much can we get out of forests and agricultural land – and what should we use it for? Is it wise to use it for conversion into automotive fuel, or should it be used for generating heat and electricity? What regulatory instruments are needed for increasing the use of bioenergy? What conflicts will there be between increased biofuel production and various environmental targets? How is the supply of food doing out in the world? And how good is bioenergy in actually preventing climate change? How do Swedish researchers view the issue?

IN SWEDISH

Är eko reko?

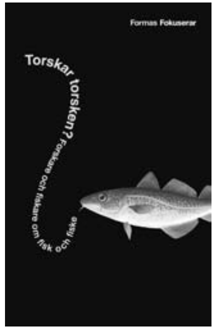
Om ekologiskt lantbruk i Sverige

Är det någon idé att köpa KRAV-märkt mat och betala lite mer? Är ekomaten verkligen bättre för hälsa och miljö? Vilka är egentligen skillnaderna mellan ekologiskt och konventionellt lantbruk? Som konsument har du rätt att få veta vad forskarna i dagsläget faktiskt vet – och varför de inte är överens.

Torskar torsken?

Forskare och fiskare om fisk och fiske

Kommer vi att kunna äta torsk i framtiden? Kan fiskodling lösa problemen? Hur ser det ut för andra arter i vattnet, som lax och kräftor? Sedan lång tid tillbaka har beslutsfattarna fått signaler från forskarna om att torskbestånden minskar. Framtidens fiske hänger på de beslut vi fattar idag. Frågan är hur stora risker vi är villiga att ta. Här finns det stora skillnader mellan olika intressegrupper. Vad säger forskarna – och vad säger fiskarna?



Genklippet?

Maten, miljön och den nya biologin

Idag kan vi förändra växter, djur och bakterier på ett nytt sätt – genom att klippa ut gener och föra över dem från en art till en annan. Är det farligt för människa och miljö när genmodifierade organismer börjar odlas och blir mat på våra fat? Eller blir gentekniken klippet som kommer att rädda världen från svält och miljöproblem? Gentekniken påverkar det levandes urgamla spelregler. Därför har den stött på hårt motstånd från europeiska konsumenter och miljöorganisationer. Men vad säger forskarna om möjligheter och risker med den nya biologin?

Forskare klargör

Myter om maten

Gräver vi vår grav med kniv och gaffel? Vad ska vi äta för att inte bli feta och sjuka? Hur hållbara är egentligen myndigheternas kostråd? Går vi vilse i pannkakan? Blir vi feta av fett, eller blir vi feta av socker? Är det bättre med stenåldersmat? Tål våra gamla gener den nya maten? Frågor som de här diskuteras intensivt i medierna. I Myter om maten är det forskare som presenterar och tolkar vetenskapliga rön. De är överens om det mesta – men långtifrån allt.

Sopor hit och dit – på vinst och förlust

Är det vettigt att vi sorterar och fraktar våra sopor hit och dit som vi gör idag? Leder det till någon verklig miljönytta - eller har vi sopsortering mera som terapi för vårt dåliga miljösamvete? Redan 1910-talets sopsorterande människa klagade på att det var bökigt att sortera. Det och mycket annat finns att läsa i en pocketbok som belyser sopsortering ur en rad olika synvinklar.

Bevara arter – till vilket pris?

Balansgång mellan ekologiska, ekonomiska och sociala aspekter

Sverige har undertecknat FN-konventionen om biologisk mångfald. Den säger att vi ska bevara den biologiska mångfalden, och använda den på ett hållbart och rättvist sätt. Riksdagen har bestämt att arter som har funnits länge i Sverige ska bevaras i livskraftiga bestånd. Risken är annars att vi utrotar arter som är viktiga för ekosystemen och för människan. Men hur ska vi göra – och vad får det kosta? Vad tycker forskarna – och vad tycker andra intressenter i samhället?

Spelet om staden

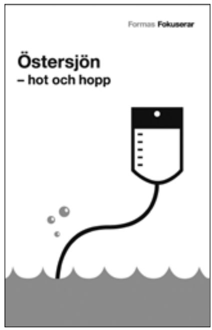
Vem bestämmer över våra städers utveckling? Staden kan ses som en spelplan med ett stort antal aktörer med olika åsikter, lojaliteter och intressen. Hur ser spelplanen ut? Vilka spelregler gäller? Och vilka är spelarna? Är städerna i första hand tillväxtmaskiner, snärjda i global konkurrens och styrda av multinationella företag? Eller kan vi uppnå hållbara städer som erbjuder alla sina invånare en hög livskvalitet utan att äventyra för framtidens människor? Forskarna har inga färdiga svar, men belyser från olika utgångspunkter de drivkrafter som formar och förändrar staden.

Djuren – i människans klor

Hur mår våra djur - i hagar, stall, lagårdar och hemma hos oss? Vad betyder de för oss? Vi både äter och älskar dem. Vad har vi rätt att använda dem till? Kan vi förstå vad de känner? Hade djuren det bättre förr? Behövs det körkort på sällskapsdjur? Hur mycket är nog när det gäller avel? Ska katter behandlas mot cancer? Är Sverige världsbäst på djurskydd? Alla de här frågorna och många fler får du svar på av forskare som skriver i boken, forskare med lite olika syn på saken.

Östersjön – hot och hopp

Larmrapporterna om Östersjön har duggat tätt de senaste åren. Men är Östersjön ”sjukare” idag än för hundra år sedan? Går det att ”rädda” Östersjön? Vilka åtgärder är vettigast? Är det bra med kväverening, eller ska vi kanske kvävegödsla? Går det att få bort fosforn från sedimenten? Kan vi syresätta bottnarna? Måste vi kanske äta mindre kött för att rädda havet? Men måste vi samtidigt också äta mindre fisk? Vad är forskarna överens om och varför kommer de till olika slutsatser?



Giftfri miljö – utopi eller verklig chans?

Kadmium i mat och kvicksilver i fisk. Nya metaller i tänder och bilar. Klorerat, bromerat, fluorerat. Nanopartiklar invaderar kroppen. Akrylamid bildas när vi tillagar maten. Läkemedelsrester dyker upp i dricksvatten. Mannens spermier skadas. Hur mycket ska vi stå ut med av gamla problem och nya hot? Varför slår vi så ofta dövörat till när larmet går? Kan vi få en giftfri miljö som riksdagens miljömål talar om? Eller är det bara en önskedröm?

Konsumera mera – dyrköpt lycka

Konsumtionen har ökat kraftigt de senaste hundra åren. Men lyckligare har vi inte blivit. Varför fortsätter vi ändå att konsumera allt mera? Hur ska vi tillräckligt snabbt lära oss att leva med den enda planet vi har? Borde politikerna se till att avskaffa alla stöd till ohållbar konsumtion? Hur stor makt har vi som konsumenter? Kan man vara både rik och miljövänlig? Eller behövs det kanske nya samhällssystem för att rädda världen? Hur ser olika forskare på saken?

Bioenergi – till vad och hur mycket?

Hur långt räcker bioenergin i framtidens energisystem? Hur mycket går det att få ut från skogar och åkermark? Är det klokt att satsa på biodrivmedel, eller ska bioenergin användas till värme och el? Vilka styrmedel behövs för att öka användningen av biobränslen? Hur går det med livsmedelsförsörjningen globalt? Och hur bra är biobränslena egentligen på att förhindra klimatförändringar? Hur ser forskarna på saken?

Ska hela Sverige leva?

Ska hela Sverige leva – och vad innebär i så fall det? Landsbygdsutveckling är ett värdeladdat ord. Men vad betyder det – och vad menas med landsbygd? Hur viktigt är jordbruk och skogsbruk för en levande landsbygd? Vilka nya landsbygdsnäringar dyker upp? Och vad betyder landsbygden för stadsborna? Kan Sverige leva utan öppna landskap? Behövs det kvinnor för att en bygd ska leva? Och vart är byarörelsen på väg? Läs vad drygt 35 forskare skriver om de här frågorna!

KliMATfrågan på bordet

Mat åt nio miljarder – hur ska vi fixa det i ett nytt klimat? Och hur påverkar maten i sin tur klimatet? Hur ska vi äta klimatvänligt? Är det moraliskt fel att äta nötkött? Ska vi producera kött utan djur för klimatets skull? Hur mycket betyder transporterna och spillet i livsmedelskedjan? I Sverige får vi nya grödor, men också nya ogräs och skadegörare. Och djuren kan bli sjukare. Vad innebär ett nytt klimat för olika delar av vårt avlånga land? Läs boken så får du veta hur olika forskare ser på saken.

Osäkrat klimat – laddad utmaning

Att jorden blir varmare beror mycket sannolikt på människans utsläpp av växthusgaser. Det säger FN:s klimatpanel IPCC – och kopplar uppvärmningen till stigande havsnivå, krympande isar och risken för snabba förändringar som inte går att förutse. Men när blir människans klimatpåverkan farlig, och vad är det som står på spel? Är EU:s energi- och klimatpolitik en tandlös tiger? Är lagring av koldioxid en lösning eller dimridå? Är hotet mot klimatet en chans för företagen? Boken innehåller artiklar av cirka 40 olika forskare.

IN RUSSIAN

Биоэнергетика – сколько и зачем?

Какую роль будет играть биоэнергетика в будущих энергосистемах и насколько ее хватит? Сколько биомассы можно взять из леса и с пахотных земель – и как это использовать? Разумно ли делать ставку на транспортные биотоплива, или лучше использовать биомассу для производства тепла и электроэнергии? Какие политические рычаги необходимы для увеличения использования биомассы? Не входит ли увеличение использования биомассы в противоречие с другими экологическими задачами? Как обстоит дело с производством питания в мире? И насколько биотоплива помогут сохранить климат?