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.

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