CARBON DIOXIDE MITIGATION AND ADAPTATION OPTIONS

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1. Introduction

At present, global society emits around 6 gigatonnes of carbon per year (GtC/yr) from combustion of fossil fuels, and 1 to 2 GtC/yr from deforestation. Over the twenty-first century, global carbon emissions are expected to increase, mainly as a consequence of income growth and population growth. Global scenario studies suggest that global emissions may reach 20 GtC/yr, although the uncertainty range is wide—emissions may fall between 5 and 40 GtC/yr by the end of the century. It should be kept in mind that these scenarios are called baseline, or business-as-usual, scenarios (i.e. they describe an assumed future in which no policies are adopted to reduce carbon dioxide (CO_2) emissions).

The atmospheric concentration of CO_2 is at present roughly 30% higher than its pre-industrial concentration. If emissions are kept constant at the present level, models of the global carbon cycle predict a doubling of the atmospheric concentration by the end of the twenty-first century. If the emissions increase over the twenty-first century, as most scenarios suggest unless carbon abatement policies are put in place, the doubling of atmospheric CO_2 concentrations will be reached even earlier.

Water vapor, CO_2, and several other gases have the property that they absorb long-wave electromagnetic (heat) radiation. This is the radiation the earth emits towards the universe. Since the atmosphere contains water vapor and CO_2, parts of this radiation is absorbed and reemitted towards the earth's surface. This means that the average annual surface temperature of the earth becomes higher than in the absence of what are called greenhouse gases. This is the natural greenhouse effect.

How much temperatures will increase depends on (i) future emissions of CO_2 and other greenhouse gases, (ii) the resulting atmospheric concentrations of greenhouse gases, (iii) future emissions of sulfur (which will temporarily but geographically and heterogeneously mask parts, but not all, of the temperature increase) and (iv) how sensitive the climate is to higher concentrations of greenhouse gases. All these factors are uncertain. For instance, the global average temperature change per CO_2-equivalent doubling is 1.5°C–4.5°C. This uncertainty range is considerable.

The expected temperature increase can be compared with the drop in global average temperature change of 5°C that was experienced during the transition to the last ice age. Stockholm Environment Institute and several other researchers refer to a global average temperature increase of 2°C as a high-risk temperature change. The European Union has also adopted a temperature increase of at most 2°C above pre-industrial levels as a long-run target for global climate change policies.

Impacts on humans, society, and ecosystems are discussed elsewhere in this encyclopedia. Here we will focus on different approaches society may employ to deal with climate change. There are two broad categories of strategies: we can either reduce the emissions or adapt to the expected and actual climatic changes. In reality, a combination of the two approaches is likely to emerge, since we are already committed to some climatic changes. For instance, even if we were to stabilize atmospheric concentrations at levels as ambitious as the present level, which would require a global cut in global emissions by 50% from the present levels, global temperature could still increase by as much as 2°C. This level of climate change would require adaptation measures to be taken throughout the world. We will first look at mitigation options and then at adaptation.

2. Mitigation Options

In this section we will consider only energy-related CO_2 emissions. Emissions of non-CO_2 gases as well as CO_2 emissions from deforestation are discussed in other articles.

There are fundamentally two different measures that can be taken to reduce CO_2 emissions: (i) reduce energy use and (ii) reduce the carbon emissions per unit of energy use. We will discuss them separately, but it should be kept in mind that measures to reduce the carbon emissions per unit of energy supply may also lead to increased energy efficiency. For instance, a carbon tax would increase the cost of using fossil fuels and consequently the price of energy. This, in turn, would strengthen the incentives to use energy more efficiently and increase the use of alternative energy sources at the expense of fossil fuels.

2.1. Reducing Energy Use

The level of energy use is determined by several factors (e.g. population, lifestyles, prevailing income levels, and how efficiently energy is being used).

2.1.1. Population

Although policies that reduce population growth are rarely discussed in the context of climate change, it could be an important policy option. The global population has already reached six billion. Near-term projections are rather robust and can be only marginally affected by family planning policies. But, over the twenty-first century, small changes in population growth may compound to differences in global population by almost a factor of two. For instance, some scenarios suggest that the global population by the year 2100 could be seven to eight billion whereas others suggest 15 billion.

A world with 15 billion people is likely to have higher carbon emissions than a world with eight billion people. But carbon emissions are not likely to be twice as high since most of the population growth is expected to occur in developing countries where per capita use of energy and CO_2 emissions are much lower than in industrialized countries. Further, concerns about climate change should not be the main driver for population policies. Rather, governments should work to improve maternal and infant health care, the status of women, and the level of education, in particular of women. Such measures have been seen to lead to reductions in fertility rates.

Sometimes, but not always, these advances have come about with higher income levels; but they have also been reached in regions where gross domestic product (GDP) per capita is very low (e.g. in the state of Kerala in southwest India). This points to the fact that income growth is not a requirement for achieving a reduction in fertility and infant mortality rates.

Finally, lower population levels would, in turn, bring about many other positive effects: pressure on the local environment in poor countries (e.g. water resources, forests, and soils) may be relieved and nutritional status may be improved if the number of small children drops. And it would also relieve, to some extent, pressure on global commons, such as the climate.

2.1.2. Income Per Capita and Prevailing Lifestyles

The main reason for the higher energy use and associated carbon emissions in USA, Europe, and other Organisation for Economic Co-operation and Development (OECD) countries is the higher levels of income in these regions. Although policies aiming to reduce income as a means to obtain lower carbon emissions are not being discussed in the policy-making community, there is a general acceptance that the main driver for the increasing carbon emissions in most, if not all, countries of the world is continued economic growth. Thus, green political parties and environmental organizations have criticized the prevailing focus on economic growth.

Clearly, it is not economic growth as such but the content of the growth that determines whether economic growth will lead to higher energy use (and potentially growing carbon emissions). This has led to a growing discussion about the way we live our lives in developed countries. Calls for lifestyle changes are being made, in favor of less resource consuming life styles (e.g. traveling less by car and airplanes, buying energy-efficient products, etc.). If this takes place, energy use would be able to be decoupled from GDP. It is particularly important to discourage the emergence of future new energy-intensive activities (e.g. space travel, to take an extreme example), since this is easier than discouraging such activities once they have emerged.

Since it is the content of economic growth rather than the number that determines the environmental impact of continued growth, policies should be directed at those impacts that cause CO_2 emissions rather than at GDP.

Finally, it is important to distinguish our standard of living from our material standard of living. Our striving for increased purchasing power has had negative consequences, such as increased stress and other illnesses. Some of these negative impacts could be reduced by a change in our lifestyle (e.g. by traveling to work by bike instead of by car). If we did so, our standard of living might improve despite a possible reduction in the material standard of living. In some cases, such decisions are difficult to make on an individual level, but they are more acceptable if there is a collective decision to move in same direction. For instance, France recently decided to reduce its normal work week to 35 hours from 40, although this might lead to losses in economic output.

2.1.3. Energy Efficiency

There are several ways of increasing energy efficiency. (1) We may adopt more energy-efficient technologies, or (2) we may implement organizational changes that lead to lower energy use levels (e.g. increasing recycling rates). These approaches are discussed below.

The first option, increasing energy efficiency, looks more specifically at how energy is supplied, distributed, converted, and used. There is much potential for energy efficiency improvements in industry, households, and the transport sector.

To understand the discussion about the potential for improved energy efficiency it is important to distinguish between theoretical, technical, and economic potential.

The theoretical potential is in many cases very large. It is difficult to establish even a lower limit for the energy supply that is required to perform a certain task. This means that the theoretical potential to improve energy efficiency is almost 100% in many cases. For instance, the minimal energy supply required to maintain the temperature in a house at a certain temperature (higher than the outdoor temperature) is equal to the losses. But the losses can be made however small you want them to be, by adding more and more insulation.

The same reasoning can be applied to the transport sector. The theoretical minimum energy supply that is needed to move a good or a person from one place to another is the difference in potential energy (which is zero if the height above sea level is the same). In theory, energy is needed only to accelerate the good or the person, but that acceleration energy can be recovered when braking. Energy is also needed to counteract friction losses (against the air and the road). However, since the speed could be arbitrarily low, friction losses and acceleration energy could be made arbitrarily low as well.

Another example is chemical processes. Here energy (or exergy to be more specific) is needed to raise the chemical potential of certain materials, for instance, reduction of iron ores into metallic iron, or bauxite into metallic aluminum. In this case it is possible to establish a minimum theoretical energy requirement, but in theory it could be released again if the iron or the aluminum were re-oxidized. However, these reactions would have to be done in a reversible manner, and that would take an infinite amount of time. Thus, if the processes should occur at a certain speed, entropy production would occur, and exergy losses (dissipation of energy) are a fact. But, as with the transport sector, it is not possible to establish a lower limit.

The technical potential is, of course, more limited. Analysts are not always clear about the exact definition of this concept. Sometime reference is made to what could be expected to be achieved at a certain point in time; sometimes focus is on the best currently available technology. It is, however, not clear that the best technologies will ever be employed on a large scale, since they may be much more costly or difficult to use than competing technologies. Well-insulated houses are a typical example. Here, the cost of additional insulation will be compared with the additional saving on energy, and if the cost of energy is low, then the demand for insulation will drop.

For this reason, the economic potential of various technologies is often discussed. The economic potential not only depends on the cost of the technology, it also depends on the interest rate, and present and expected energy prices. If the cost of energy is expected to jump in the future, the economic potential for energy efficiency improvements will increase.

It has been shown that technologies that have the economic potential to be widely used nevertheless fail to be adopted on a large scale. This is often explained by the fact that incentives for energy efficiency are sometimes distorted (those who rent apartments are different from those who own them), the possibility that consumers have inconsistent requirements on pay-back times (e.g. in certain studies consumers were found to require internal rates of returns of as much as 60% while the same consumers at the same time were saving money in bank accounts with interest rates less than a few percent), consumers lacking information about more energy-efficient products, and minor differences between the products that consumers paid more attention to than what was initially believed.

Some analysts believe these barriers can be removed at rather low costs. This would then imply that substantial carbon abatement could be achieved at low costs. Others claim that there are substantial costs associated with the removal of these barriers, which explains why several energy-efficient technologies have not been adopted by the market.

Organizational changes to improve energy efficiency: Organizational changes could involve a change in the transport system to trains and ferries. Public transport systems could be improved to be more important for commuting and personal transport. We could also reconsider the way cities are planned and where production facilities are located. This is particularly important in developing countries where new infrastructures are emerging. These infrastructures are very long lived, and making the right choices now could make these societies less energy intensive for a long time to come. Using information technologies, we could work more at home and thereby reduce personal transport. Other examples include increased recycling rates of steel and aluminum. This would save substantial amounts of energy.

Historic and future trends in energy efficiency and energy intensity: Energy efficiency has generally increased over time. Typical examples can be found in electricity generation (i.e. the efficiency by which thermal energy is converted into electric energy) and process industries in general (e.g. steel and aluminum production). Electricity generating efficiency in the beginning of the twentieth century was as low as

2.3. Conclusions

One important conclusion that should be drawn from this presentation of energy efficiency and energy supply options is that there are large technical opportunities to reduce CO_2 emissions. Energy efficiency might reduce the need to supply energy, and the energy supply may come from decarbonized fossil fuels or from renewable energy sources. Still, in order for this happen there is a need for policy intervention where governments introduce economic incentives to use these emerging technologies.

3. Adaptation

Even if all the mitigation options were employed at the largest possible scale, we must still expect certain climatic changes. For instance, a very ambitious carbon abatement program, such as stabilization at 350 parts per million (ppm) CO_2, might cause an increase in the global average annual surface temperature as much as 1°C–2°C or more. Thus, we need to think not only about mitigation but also about how we should deal with the climatic changes that are already on their way.

Adaptation describes the way ecological, social, and economic systems respond to actual or expected climatic changes. In this section, we will limit the discussion to adaptation by human beings and the ecosystems managed by human beings. Adaptation by natural, unmanaged ecosystems is most often discussed under the heading of ecological impacts.

By adapting to climate change, we may be able to reduce the expected damage. For instance, if the climate becomes drier, farmers can be expected to employ less water-intensive irrigation techniques. This would improve the situation for farmers over a situation where no such adaptation measures were taken. This example of an adaptation option may serve to illustrate our discussion on various aspects of adaptation.

There are several types of adaptation. Adaptation may be autonomous or planned, passive or anticipatory, and may be carried out by governments or private actors.

Autonomous adaptation (sometimes also referred to as spontaneous adaptation) is generally defined as the kind of adaptation that takes place without the interference of governments (national or local) in response to actual climatic changes (e.g. farmers changing irrigation techniques in response to a drier climate).

Adaptation may also be initiated by governments (at any level). In these cases, it may be either anticipatory (taking place in response to expected changes) or passive/reactive (taking place in response to past changes). Planned anticipatory adaptation may involve government policies to encourage farmers to start cultivating other crops that are more suited to the expected climate, or more resistant to extreme events (if that is what is expected). Reactive adaptation would take place if that change of crop took place after the climate had changed. In reality, it might be difficult to distinguish these two types of adaptation, particularly if the climate is continuously changing.

Further, when assessing the costs of climate change, it is important to keep in mind that even if the introduction of more water-efficient irrigation techniques is judged optimal, there may still be costs associated with it. And there may be costs associated with the residual damages. The level of adaptation can in most cases not be expected to be so complete that all negative climatic impacts are avoided. Thus, there might be both costs of adaptation and costs of the remaining climatic damages.

Another key issue is adaptation to what? Estimates of climate change are often discussed in terms of key global indicators, such as changes in annual average global surface temperatures, or regional aggregate indicators, such as changes in average annual precipitation or sea-level rise. It is therefore all too common for adaptation studies to focus on these aggregate variables. But changes in the frequency and magnitude of extreme impacts are equally important as changes in averages, if not more so. For instance, over the twentieth century, precipitation in the U.S. increased by 10%, but half of this annual increase was distributed in the top decile of rainfall intensity. Thus, the consequences of this additional rainfall are different from if it had been more evenly distributed over the year. Similarly, the best way of adapting to this additional rainfall is different from adapting to a different distribution.

In integrated assessments or impact studies of climate change, the way adaptation takes place is a key determinant of the expected costs of the changes. The first generation of studies generally did not assume any adaptation at all. This tended to overestimate the expected costs of climate change. More recent studies have criticized the earlier studies.

In reality, human beings will change their behavior in response to the changing climate, and it is therefore important that these changes are included in the impact studies. Thus, the assumption about non-adapting agents, sometimes referred to as the assumption of "dumb farmers," has been replaced by an assumption about agents that adapt optimally to the changing climate. This assumption reduces the costs of climate change substantially.

However, this assumption is also unrealistic. Given the large uncertainties about how climate will change, it is reasonable to expect time lags between when changes start to take place and when agents begin to adapt, since natural variability will tend to mask ongoing longer-term changes in the climate. One could also expect that this natural variability will induce misadaptations (e.g. a few years of recurrent summer droughts may be taken as evidence that a much drier climate is on its way, leading farmers to overreact).

Recent studies have attempted to include a more realistic description of how various agents react to the changing climate (where natural variability masks the underlying trend). In these studies, the benefits of adaptation are clearly lower than the benefits where agents have perfect foresight and adapt optimally. But there are still considerable benefits that can be derived from adaptation compared to no adaptation.

The number of possible adaptation options is very large, and all sectors have their sector-specific adaptation options. For instance, agricultural adaptation options include opening new lands, changing seeds, developing new seeds, changing tillage systems, changing irrigation infrastructure and equipment, and building dams.

One critical issue is to what extent we should reduce emissions or adapt to climate change. It is sometimes pointed out that there are tradeoffs between the two: there are limited resources for climate policies and the available resources should be used where the payoff is as large as possible.

On the other hand, this view does not consider the distribution of the costs of emission reduction and the cost of adaptation. For instance, Sweden has a carbon tax that reduces its emissions. Some would argue that this carbon tax is costly to the Swedish economy. But even if we assume this to be correct, it does not necessarily mean that there are fewer economic resources available for adaptation to climate change in Africa in the year 2030. The potential savings Sweden could make by reducing its carbon tax are most likely to be consumed by Swedes. Given this perspective, it is not correct to argue that we should not reduce emissions today because such emission abatement would reduce the amount of economic resources available for adaptation in the future.

The impacts of climate change on human beings depend not only on the degree of climate change, but also on the degree of socioeconomic development. A drought in Europe does not lead to starvation, whereas it might in Africa. The reason for this is two-fold. First, in well-functioning democracies, governments are much more sensitive to the well-being of their citizens. Second, the level of economic development in Europe is so high that an affected country can cope with the losses: (i) there are few farmers, and they are insured so that they can be compensated for their loss of income, and (ii) the reduction in food output may be compensated by imports from other countries/regions.

Still, it must be noted that the economic costs of the drought might be larger if it affected Western Europe, since the loss in crop output might be larger given the larger yields.

The implications are important: adaptation in the sense of developing well-functioning democracies and institutions (e.g. health capacity, insurance against losses in crop yields, etc.) and achieving economic development can not be underestimated as means of reducing the impacts of climate change.