# ECONOMICS OF POTENTIAL CLIMATE CHANGE

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## Contents





## Summary

This paper contains a study on the socioeconomic impacts of climate change, and in particular provides an analysis of the damage cost caused by the greenhouse effect. The impacts on agriculture strongly depend on the adaptability of farmers, and on the reaction of markets and politics. Climate change scenarios exerted a slight-to-moderate negative impact on simulated world cereal production, even when the beneficial effects of carbon dioxide ($CO_2$), farm adaptations, and future technological yields improvements were taken into account. The extent to which forests and woodlands will be affected by climate change depends on various factors, for example, species, age of trees, possibilities for forest to migrate, and the quality of forest management. Climate change impacts are likely to exacerbate existing effects on fish stocks, notably overfishing, diminishing wetlands, pollution, and ultraviolet-B radiation. The impacts on manufacturing industry are mainly indirect through the market price changes of products from the primary sectors; direct impacts on construction, transportation and tourism are analyzed. Fossil fuels, used for space heating, will decline, while an average increase in electricity demand is predicted. The supply of water will be affected, mainly through the change in precipitation patterns, in coastal areas, through the intrusion of saline water into freshwater demand. The cost of sea-level rise includes capital costs of protective constructions or costs of forgone land services, depending on the projected policy. Global climate change has various effects upon human health: increase in the

rate of occurrence of heat-related accidents, malaria, and secondary health impacts of worsening air quality. Increased frequency and magnitude of extreme events is often mentioned as a potential characteristic of future global climate. The causes and consequences of global climate change are not evenly distributed. Those parts of the globe that contribute most to climate change are not the ones that suffer most from the consequences. The political response for balancing this situation is the United Nation Treaty on Climate Change, the Kyoto Protocol, which requires industrialized countries to reduce their greenhouse gas emissions. The future of the treaty is still uncertain (2001): many countries are not ready or not willing to fulfill the emission reduction, because it is likely to slow down economic growth. The decade long debate will continue; meanwhile public awareness will increase, owing to the impacts (e.g., most likely flooding or storm damage) of climate change.

## 1. Introduction

Economic progress has long been recognized to involve potential adverse environmental side effects at local, regional, and even global level. In recent years it has become increasingly clear that expanding economic activity can also cause environmental damage that is irreversible over long time horizons. The central theme of this paper is to study the socioeconomic impact of climate change. Assessment of policy options for climate change requires detailed information on costs and benefits of various alternative policy measures. This study is not focusing on costs of policy options but on damages and impacts of climate change. An essential element in the question of how climate change will affect the socioeconomic system is the degree of adaptation of various categories of economic activities, such as agriculture, forestry, industrial and energy systems, and coastal protection.

This study will provide an overview of research results on the impacts of climate change associated with an atmospheric $CO_2$ concentration of twice the preindustrial level ($2 \times CO_2$). This $2 \times CO_2$ is an arbitrary benchmark, chosen for analytical convenience. It is neither an optimal point nor a steady state, and warming will continue, and in fact aggravate beyond $2 \times CO_2$. The IPCC (see *Intergovernmental Panel on Climate Change*) predicts that $2 \times CO_2$ will lead to an (equilibrium) increase in global mean surface temperature of 1.4 to 5.8 °C. By 2100, sea level is projected to increase by 9 to 88 cm, with a best estimate of 50 cm, as a result of climate change. This increase comes on top of the present trend of 20 cm per century. In addition, changes will occur in the frequency and intensity of some extreme climate phenomena. Attempts at a monetary quantification of impacts—despite being a classic application of environmental economics—have started to emerge only recently. This paper will include order of magnitude estimates of impacts on the primary sectors, namely agriculture, forestry, and fishery; and impacts on industry, energy, and water supply. Further subsections will provide order of magnitude estimates of the impacts of climate change on sea-level rise, associated capital loss and protection costs, dryland and wetland loss and species, ecosystems and landscape losses, human amenity, health and mortality, and risks of disasters. The final section includes a cost benefit analysis of measures to combat global warming. Figures are presented for different geopolitical regions as well as the world as a whole and concern also the impact of adaptation measures on damage due to climate change.

## 2. Damage Cost Implications for Sectors

### 2.1 Agriculture

The impact of enhanced greenhouse effects on agriculture is ambiguous, despite large research efforts in the past decade. All impacts strongly depend on the adaptability of farmers and on the reaction of markets and politics. Together with the costs of sea-level rise the effects on agriculture are probably the most studied aspect of enhanced greenhouse effects (see *Climate Change and Agriculture*). Studies presently do not include changes in insects, weeds, and diseases; direct effects on livestock; changes in soil-management practices; and changes in water supply for irrigation. Much of this research concentrates on productivity or output aspects and does not include the impact of changing prices. Price effects, however, are crucial for economic valuation of agricultural damage. Elevated $CO_2$ may lead to more carbon stored in the vegetation. Through an increased root growth it may lead to an elevated carbon pool in the soil, too. Consequences for the total carbon balance may be considerable. The estimates of the costs to agriculture are presented in Table 1, which includes price effects, but neglects managerial responses as well as impacts of $CO_2$ fertilization. Two scenarios show the potential impact of climate change on crop yields. These data are fed into a "world food model" to analyze the effects on world agricultural markets. Welfare changes (measured as changes in producer and consumer surplus) can occur in two ways: firstly by a change in a region's agricultural output due to different climate conditions, and secondly by a change in world prices. The welfare effects (as a percentage of gross domestic product (GDP)) for the two scenarios considered in the study are reproduced in Table 1.

| Range of welfare change (% GDP[a]) | | | Average welfare change ($10^9$ \$[b]) |
|---|---|---|---|
| EU | –0.400 | –0.019 | –0.9666 |
| US | –0.310 | +0.005 | –0.7392 |
| Ex-USSR | –0.520 | +0.032 | –0.6185 |
| China | –5.480 | +1,280 | –0.7812 |
| OECD | 0.316 | –0.018[c] | –2.3130 |
| World | –0.470 | +0.010 | –3.9141 |

[a] Range from the two scenarios of Kane et al. (1992).
[b] For the ex-USSR, the result is based on gross national product (GNP) rather than GDP.
[c] Average over several subregions.
Source: Fankhauser, 1995.

Table 1. Costs to agriculture ($2 \times CO_2$—$10^9$ US\$, 1988)

Data for "upper and lower bounds" are generated from two scenarios. The results for average welfare change are significantly negative for all regions, but discrepancies between the two scenarios are considerable. This is particularly the case for China, where impacts range from a loss of more than 5% to benefits of over 1% of GDP, and to a lesser extent for the former USSR. It should be emphasized, however, that the "upper bound" case particularly is quite optimistic. It assumes non-negative yield effects in most regions. The first scenario assumes negative yield effects even for northern regions such as Canada and the former USSR, where the rising temperature most likely enlarges the agricultural possibilities. Some of the long-term scenarios assume 10 °C global temperature increase. Several crop types could reach the "upper bound" of their temperature tolerance. Also, evapotranspiration tends to rise more than linearly with temperature, and the decreasing soil moisture likely results in decreasing yields.

How fast farmers will adapt, and under which circumstances adaptation will be successful, is a crucial, but largely unknown, determinant of the damage costs. Cropping practices including crop rotation, tillage practices, and nutrient management are quite effective in combating or reversing deleterious effects. Scientific studies will tend to overestimate the damage if no adaptation is assumed. This bias is sometimes called the "dumb-farmer scenario" to suggest that it omits a variety of adaptations that farmers customarily make in response to changing economic and environmental conditions. Omitted variables are the effect of extremes and ranges in climatic variables as well as the effect of changes in irrigation. Another bias arises in the production-function approach, because it fails to allow for economic substitution as conditions change. Recent studies increasingly emphasize other (non-climate change) stress factors and the need for integrated assessment of damage. The rate of change may be equally important, as are the speed of adaptation and restoration. Moreover, changes in socioeconomic vulnerability are as important as the actual shape of the damage function. In addition to adaptation, vulnerability will change exogenously to climate change. Physical production potential is the driving force for agricultural production. Land-use change is excluded from adaptation. Climate change scenarios near the high end of the IPCC range of doubled-$CO_2$ warming exerted (in most cases) a slight-to-moderate negative effect on simulated world cereal production, even when the beneficial direct effects of $CO_2$, farm-level adaptations, and future technological yield improvements were taken into account. The only scenario that increased global cereal production was one involving major, and possibly costly, changes in agricultural systems, for example installation of irrigation.

Climate change was found to increase the disparities in cereal production between developed and developing countries. Whereas production in the developed world benefited from climate change, production in developing nations declined. The most vulnerable regions are sub-Saharan Africa, Southeast and South Asia, tropical areas of Latin America, and the Pacific Islands. Adaptation at the farm level did little to reduce the disparities, with the developing world suffering the losses. Cereal prices, and thus the population at risk from hunger, increased despite adaptation. The number of people at risk of hunger is estimated at 640 million or 6% of the total population in 2060 (compared to 530 million in 1990, 10% of total current population). The largest negative changes in cereal production occur in developing regions, though the extent of decreased production varies greatly by country depending on the projected climate. Price increases resulting from climate-induced decreases in yield are estimated to range between 24 and 145%. These increases in price affect the number of people at risk of hunger. Their estimated number increases by 1% for each 2–2.5% increase in prices (depending on the climate change scenario). People at risk of hunger increase by 10% to almost 60% in the scenarios tested, resulting in an estimated increase of between 60 million and 350 million people in this condition (above the reference scenario projection of 640 million) by 2060. Even a high level of farm-level adaptation in the agricultural sector did not entirely prevent such negative effects. In fact, in developed countries there is a significantly lower estimated impact of global warming on agriculture, and even without $CO_2$ fertilization, global warming may have economic benefits for agriculture in some regions.

## 2.2 Forestry

Many of the world's forests are amongst the last ecosystems on Earth that remain relatively undisturbed by human influences. Especially in the tropics, they harbor the majority of the world's biodiversity. As such, they are indispensable, self-maintaining repositories of genetic resources. Forests are of great socioeconomic importance as a source of timber, fiber for pulp for paper production, fuel and for many nonwood forest products. Forests are also of special economic and spiritual importance to many indigenous people. As components of the climatic system, forests play a major role in the present and projected future global carbon budget. They also influence ground temperatures, evapotranspiration, surface roughness, cloud formation, and precipitation. Roughly one-third of the world's land surface is covered by forests or woodlands. The extent to which this area will be affected by climate change depends on various factors such as the species and age of trees, possibilities for forests to migrate, and the quality of forest management. The impact of global warming on wood production is therefore ambiguous (see *Cost Implications for Forestry*). The IPCC assumes that although net primary productivity may increase, the standing biomass might not increase. Regional impacts will be strongly influenced by the extent to which forest zones can shift northwards.

Table 2 shows the reduction in forest areas implied by certain assumptions. It was assumed that 40% of all forest areas are tropical, and no tropical forests can be found in OECD (Organization for Economic Cooperation and Development) countries, the ex-USSR, and China. Therefore, in the five regions EU, US, China, ex-USSR, and OECD, forest areas uniformly decrease by 9.6%. Estimates of the value of forest are in the range US\$11 000–\$37 000 km$^{-2}$, based on observed differences in land values before and after logging. This figure is roughly in line with the ratio of income from the forest sector relative to forest areas in countries with comparatively small forest areas like Germany or France. It is, however, more than an order of magnitude too large for a country with wide forest areas, such as Canada. A small number of countries report forestry income in their national income statistics. From these data an average forest value of about US\$20 000 km$^{-2}$ was deduced. Forty percent of all forest areas are growing—those in the tropics—and the remaining 60% are decreasing. Internationally, the shift toward tropical, and away from boreal and temperate, forests suggests that most developing countries would experience relatively less forest loss than would the mid- to high-latitude countries.

| | **Loss in forest area (100 km$^2$)** | **Forestry loss ($10^6$ US\$)** |
|---|---|---|

| | | |
|---|---|---|
| EU | 52 | 104 |
| US | 282 | 564 |
| Ex-USSR | 908 | 363 |
| China | 121 | 24 |
| OECD | 901 | 1801 |
| World: | 1235 | 2005 |
| Temperate | 2169 | 2284 |
| Tropical | –934 | –279 |

Source: Fankhauser, 1995.

Table 2. Damage to the forestry sector (100 $km^2$ and $10^6$ US$, 1988)

IPPC estimates show that as a consequence of $2 \times CO_2$ the worldwide forest area could reduce by about 6%. Temperate and boreal forests would decline more, by about 16%, whereas tropical forest areas would expand by some 9%. The United States Environmental Protection Agency (EPA) estimates 40% decline of boreal forest, 1.3% reduction of temperate forest and 12% increase of boreal forest. They assume temporal forest migration northward by 600 to 700 km over the twenty-first century from global warming, and the southern boundary could move by 1000 km. Increasing losses are reported due to forest fires.

Given the current degree of uncertainty over future climates and the subsequent response of forest ecosystems, adaptation strategies (those enacted to minimize forest damage from changing environment) entail greater degrees of risk than do mitigation measures (those enacted to reduce the rate or magnitude of the environmental changes). The figures are inexact in several ways. First, they are based on an equilibrium assessment of $2 \times CO_2$ damage, that is, after enough time has passed for forests to migrate or adjust. The slow adjustment speed of forest systems may cause a temporary decline in forested areas over 200–300 years, before a new equilibrium is reached. The estimates would in this respect be too optimistic. On the other hand, they neglect the managerial response from the forestry industry, which may help to ease both transitional and equilibrium losses. On a conceptual level it should be noted that the approach used for generating data is only an approximation of the exact welfare changes to producers and consumers. A more accurate analysis would have to be based on a general equilibrium assessment which allows for price changes as well as trade effects. Finally it should be noted that the valuation is restricted to timber benefits, and neglects non-timber aspects like, for example, the aesthetic or recreational value of forests. To some extent these will be included in the figures on ecosystem loss.



## 2.3 Fisheries

The fishing industry will be affected by both the rise in sea level and the changing climate itself. Of the coastal infrastructure threatened by sea-level rise, a large proportion can be associated with fisheries (see *Cost Implication for Fisheries*). Climate change impacts are likely to exacerbate existing effects on fish stocks, notably overfishing, diminishing wetlands and nursery areas, pollution and ultraviolet-B (UV-B) radiation. Globally, saltwater fisheries production could be unaffected by climate change and it could be significantly higher if management deficiencies are corrected. Also, globally, freshwater fisheries and aquaculture at mid to higher latitudes should benefit from climate change. Even without major change in atmospheric and oceanic circulation, local shifts in centers of production and mixes of species in marine and fresh waters are expected as ecosystems are displaced geographically and change internally. While the biological relationships are not well understood, positive effects should be offset by negative factors such as a changing climate, which alters established reproductive patterns, migration routes, and ecosystem relationships. Where ecosystems are changing, economic values can be expected to fall until long-term stability (i.e., at about present amounts of variability) is reached. National fisheries will suffer if institutional mechanisms are not in place which enable fishers to move within and across national boundaries. Subsistence and other small-scale fishermen, lacking mobility and alternatives, are often most dependent on specific fisheries and will suffer disproportionately from changes. Of particular importance for the fishing industry could be the loss of coastal wetlands. Wetlands serve as habitat or breeding ground for various species and, through the food chain, changes in this area could easily spread. A 50% reduction in marsh productivity (for any reason) would lead to a 15–20% loss in estuarine-dependent fish harvests. Given an expected loss of about 33% of all coastal wetlands, a loss of 10–13% in estuarine-dependent fish harvests can be expected. Estimates show that about 68% (by weight) of all commercially harvested species in the US are in some way estuarine dependent. This would imply a reduction in total catches of 7–9% in the US. Assuming that the average of 8% holds worldwide, reductions in annual catches as shown in Table 3 can be derived. However, the estimates for wetland loss will include the damage to commercial fisheries.

| | **Nominal catches (1988, 1000 t)** | **8% reduction (1000 t)** |
|---|---|---|
| EU | 6 977 | 558 |
| US | 5 656 | 452 |
| Ex-USSR | 10 171 | 814 |
| China | 5 806 | 464 |
| OECD | 31 288 | 2 503 |
| World | 85 358 | 6 829 |

Source: Fankhauser, 1995.

Table 3. Reduction in fish harvests (1000 tons, 1988)



A tentative impact ranking can be constructed, with the first item being impacted the most: (a) freshwater fisheries in small rivers and lakes, in regions with larger temperature and precipitation change; (b) fisheries within Exclusive Economic Zones (EEZs), particularly where access regulation mechanisms artificially reduce mobility of fisher groups and fleets and thus their capacity to adjust to fluctuations in stock distribution and abundance; (c) fisheries in large rivers and lakes; (d) fisheries in estuaries, particularly where there are species without migration or spawn dispersal paths, or estuaries impacted by sea-level rise or by decreased river flow; and (e) high sea fisheries. Adaptation options providing large benefits irrespective of climate change are: (a) design and implement management institutions which recognize the finite, varying nature of the resources and the different social and economic organization of fisheries, and which promote economically efficient harvesting; (b) support innovation by research on management systems and aquatic ecosystems; (c) expand aquaculture to increase and stabilize seafood supplies, to help stabilize employment, and to carefully augment wild stocks; (d) in coastal areas, integrate the management of fisheries with other uses of coastal zones; and (e) monitor health problems (e.g., red tides, ciguatera, cholera) which could increase under climate change and harm fish stocks and consumers.

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