



CLIMATE CHANGE AND FINLAND

SUMMARY OF THE FINNISH RESEARCH PROGRAMME ON CLIMATE CHANGE (SILMU)



WHAT WAS SILMU?

Anthropogenic impacts on the Earth's atmosphere are expected to cause significant global climate changes during the next few decades. These changes will have many consequences both in nature and on human activities.

In order to investigate the implications of such changes in Finland, a six-year multidisciplinary national research programme on climate and global change, the Finnish Research Programme on Climate Change (SILMU), was initiated in 1990. Its principal goals were:

- to increase the knowledge of climate change, its causes, mechanisms and consequences
- to strengthen research on climate change in Finland
- to increase the participation of Finnish researchers in international research programmes
- to prepare and disseminate information for policy makers on adaptation and mitigation.

The key research areas were: 1) quantification of the greenhouse effect and the magnitude of anticipated climate changes, 2) assessment of the effects of changing climate on terrestrial and aquatic ecosystems, and 3) development of mitigation and adaptation strategies.

There were eighty individual research projects in SILMU, involving approximately two hundred scientists from seven universities and eleven research institutions. In addition to research work carried out by individual projects, the implementation strategy of SILMU included the integration of research groups and scientific disciplines into multidisciplinary working groups, the establishment of various co-ordinating mechanisms, and interdisciplinary reporting.

SILMU was funded directly from the state budget: 12 million Finnish marks (about 2.5 million USD) in 1990 and 15 million FIM (3 million US dollars) annually from 1991–1995. The research programme was completed in 1995.



THE CHANGING ATMOSPHERE

THE ENHANCED GREENHOUSE EFFECT

Some gases in the atmosphere strongly absorb the infrared radiation emitted by the Earth, but do not affect the passage of incoming radiation from the Sun. Like the glass in a greenhouse, these gases produce a natural warming effect – the greenhouse phenomenon – which keeps the Earth's surface some 33 degrees Celsius warmer than it would otherwise be without an atmosphere.

The most important greenhouse gases are water vapour and carbon dioxide (CO_2). Other atmospheric absorbers of infrared radiation include methane (CH_4), nitrous oxide (N_2O), halocarbons and ozone (O_3). All of these gases occur naturally in the atmosphere except halocarbons, which are exclusively of human origin.

However, human activities are increasing the amount of many greenhouse gases in the atmosphere. The concentration of carbon dioxide has increased by 20 per cent during this century and that of methane by 70 per cent. This produces a perturbation to the energy balance of the Earth referred to as "radiative forcing" and expressed in units of watts per square metre.

The positive radiative forcing due to greenhouse

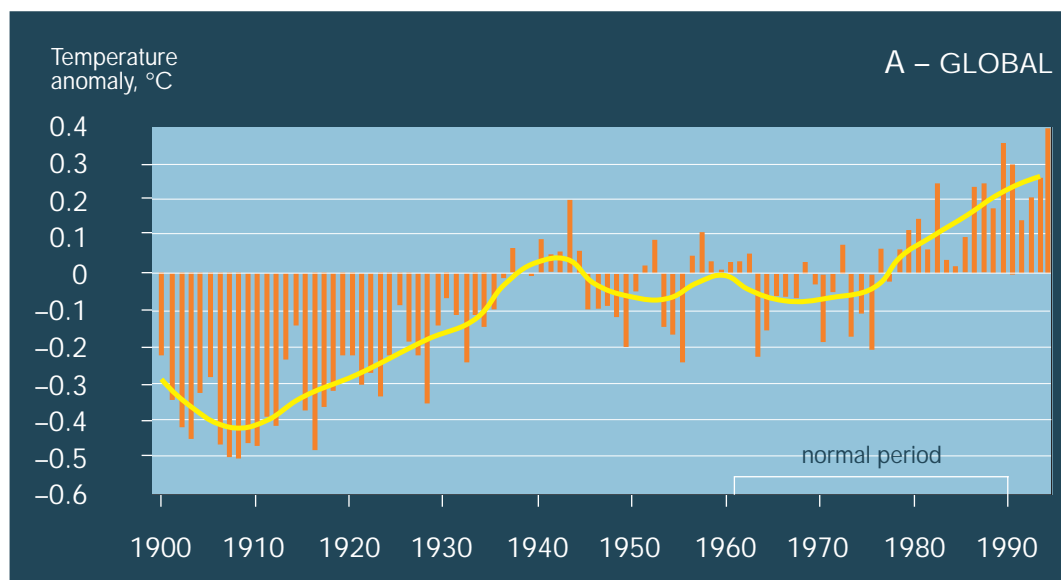
gases has been predicted to lead to an enhancement of the greenhouse phenomenon, and a consequent rise in surface temperature and other associated changes in climate. The predictions are supported by an observed increase in global mean temperature of about 0.3 to 0.5 degrees Celsius since the late nineteenth century (Fig. 1A), leading the Intergovernmental Panel of Climate Change (IPCC) to state in 1995 that "the balance of evidence suggests that there is a discernible human influence on global climate".

Aside from their radiative effects, increases in some of these gases may have other consequences. For instance, ground level ozone concentrations are relatively high in Finland. They regularly exceed the values considered safe for vegetation in spring and in summer, though they rarely reach levels deemed harmful to humans. On the other hand, enrichment of carbon dioxide is known to stimulate the growth of many plant species and improve their water use efficiency.

AEROSOLS

The industrialised countries have contributed to an increasing atmospheric load of sulphate aerosol particles from the burning of fossil fuels. The increase is found predominantly over the main source areas. For example, over large areas of central Europe sulphate

Fig. 1. Global and Finnish annual mean temperatures, 1901–95, given as anomalies from the mean of the normal period 1961–90.



concentrations are more than ten times their pre-industrial levels. A smaller but significant increase has also occurred in Finland.

Developing countries also release particles into the atmosphere, by biomass burning and by dryland cultivation. The direct radiative forcing of all human-derived aerosol sources has been estimated to be about -1.0 W m^{-2} , that is, a cooling effect. This cooling partly compensates the greenhouse gas forcing, estimated at $+2.5 \text{ W m}^{-2}$.

Both these values are averages over the Earth's surface. However, the cooling effect by aerosols mainly occurs near the source areas, while the enhanced greenhouse effect has an almost even global distribution. In addition, the atmospheric lifetime of aerosol particles typically varies from a few days to a few months. Most greenhouse gases remain in the atmosphere for tens or hundreds of years.

OZONE DEPLETION

A key factor in the depletion of stratospheric ozone, which protects all life on Earth from harmful ultraviolet radiation from the Sun, has been the release of halogenated hydrocarbons. These include chlorine-containing chlorofluorocarbons (CFCs) and halons, which contain bromine. All of these are also effective greenhouse gases.

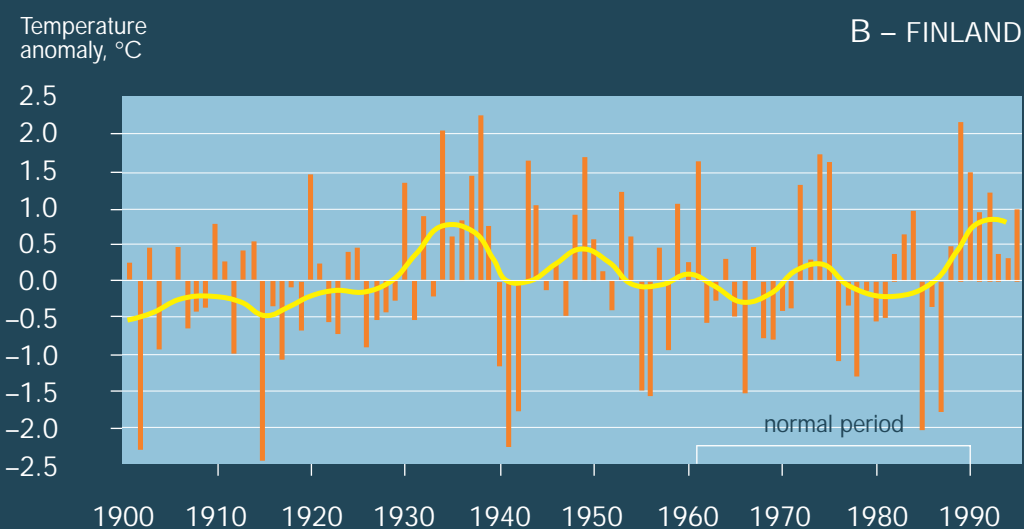
The most obvious feature of ozone depletion has been the appearance of the Antarctic ozone hole in September and October. In recent years the same phenomenon has been observed during the northern spring in the Arctic. Over some locations in Finland ozone depletion at the altitude of the ozone maximum, around 20 km, has been as high as 60 per cent. Since 1979, the mean stratospheric ozone content over Finland has declined by 10 per cent.

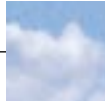
Recent international agreements have led to the phasing out of production and use of CFCs. However, their substitutes, the hydrofluorocarbons (HFCs), are also effective greenhouse gases. In Finland, the use of CFCs decreased from about 3000 tonnes to less than 500 tonnes per annum over the period 1987–94.

CLIMATE IN FINLAND SINCE THE LAST GLACIATION

Climatological observations have been made in Finland during about the last 150 years. Proxy data on climate can be obtained for much longer periods. In SILMU, the annual growth of pine trees in Lapland was used as a proxy indicator of summer temperatures. Ice cores from Greenland have also been used to evaluate the past climate variations in northern Europe.

About 11 500 years ago the climate in Scandinavia





warmed rapidly, marking the end of the last Ice Age. The warming continued and two millennia later Europe was about as warm as today. About 5 000 years ago a cooling trend began. The pine forests in Lapland receded; the tree-ring record indicates that this also was a period of unstable climate.

The most significant climatic variations during the last millennia have been the medieval warm period (900–1300) and the Little Ice Age (1550–1850). The former was slightly warmer than the present day in Finland, the latter about one degree Celsius cooler.

FINNISH CLIMATE DURING THIS CENTURY

In many areas of Europe a warming trend has been observed during this century. On the other hand, temperatures in the North Atlantic have declined. In Finland the changes have not been very clear (Fig. 1B). Annual averages based on eight representative weather stations indicate a statistically significant warming of about half a degree during this century, but variations from year to year are large.

In the early decades of this century temperatures rose and were particularly high in the 1930s. This was followed by a cooling period until the 1970s, after which a rising trend has dominated. However, recent temperatures have not yet surpassed the maximum of the 1930s.

The most notable variations in precipitation during this century include the wet years of the 1920s and early 1930s and the dry 1940s. Since the 1950s there has been a weak upward trend in precipitation. By far the driest year of this century was 1941; the wettest years have been 1981 and 1974.

It is generally difficult to detect statistically significant long-term trends in climate over northern Europe because of the high inter-annual variability of climate. This high variability may also affect people's attitudes and perceptions of the climate change issue.

CLIMATE CHANGE SCENARIOS FOR FINLAND

Global climate models (GCMs) are commonly used to estimate future climate, but there are many uncertain-

ties in their predictions. These arise from an inadequate representation of different components of the climate system, such as clouds, air-surface interactions and ocean circulation. In addition, predictions of future climate are closely dependent on projections of atmospheric composition, which are largely governed by anthropogenic emissions of greenhouse gases and aerosols and are also uncertain.

Three scenarios of temperature and precipitation change were developed for SILMU based on GCM results over Finland: a central "best guess" scenario and lower and upper estimates representing an uncertainty range (Fig. 2).

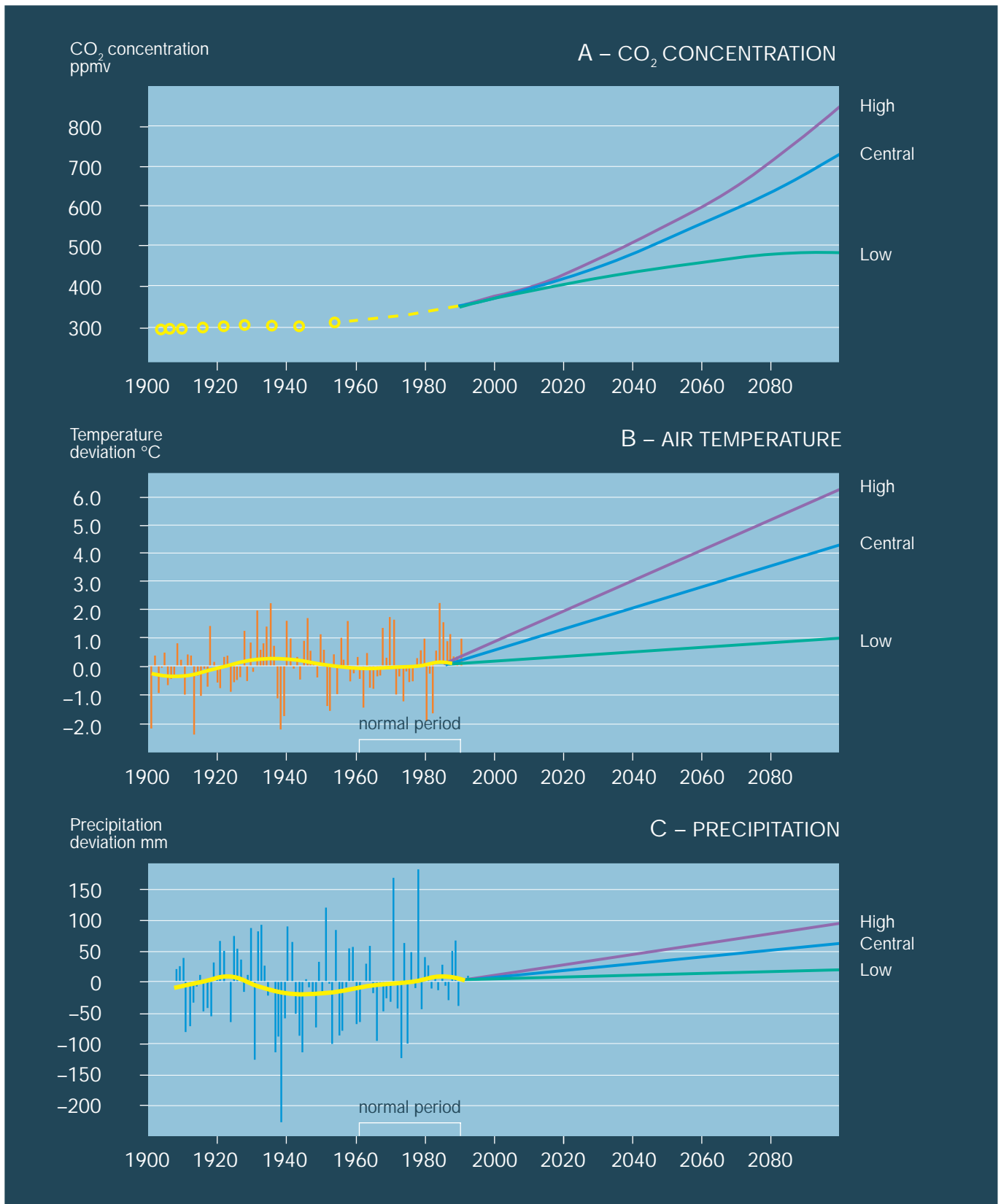
The central temperature scenario gives a mean annual warming of 2.4°C by 2050 and 4.4°C by 2100. This is about one and a half times greater than the average global warming expected over the same period. Under the low scenario the corresponding values are 0.6°C and 1.1°C, and under the high scenario, 3.6°C and 6.6°C, respectively. Warming is expected to be greater in winter than in summer.

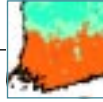
Predictions of precipitation are much more uncertain than those of temperature. The SILMU central scenario for annual precipitation is an increase of 1% per decade (2% per decade in winter and 0.5% per decade in summer). This represents an annual increase of about 30–40 mm by 2050 and 60–70 mm by 2100 in southern Finland. Under the low scenario the increase is 0.5% per decade and under the high scenario, 1.5% per decade. Because these scenarios are scaled relative to the temperature scenarios, they do not reflect all of the uncertainties in GCM estimates.

Scenarios of future atmospheric carbon dioxide concentrations were also provided, since CO₂ is known to affect plant growth and water use. The central scenario gives concentrations of 523 ppm by 2050 and 733 ppm by 2100. The corresponding values are 456 ppm and 485 ppm for the low scenario and 555 ppm and 848 ppm for the high scenario.

No scenarios for other meteorological variables were developed.

Fig. 2. The central, low and high SILMU scenarios of carbon dioxide (absolute), air temperature and precipitation (relative to the 1961–90 mean) for the period 1990–2100. These scenarios were used in all SILMU projects to estimate the impacts of climate change in Finland. Also shown are the historical values from 1900 of CO₂ (global), air temperature (mean of eight stations in Finland) and precipitation (mean of 24 stations).





IMPACTS OF CLIMATE CHANGE IN FINLAND

The potential effects of the SILMU scenarios on natural ecosystems and economic activities in Finland were evaluated using a range of approaches, including experimentation, mathematical modelling and expert judgement. The main focus of studies was on land ecosystems, including forests, peatlands and agriculture, and aquatic ecosystems, including inland waters and the Baltic Sea.

FORESTS

The total annual growth of Finnish forests has been almost 80 million m³ in recent years, with a total growing stock of around 1900 million m³. Annual growth is expected to increase by over a third within a few decades. Part of this increase will be due to improved forestry, part will be caused by higher atmospheric CO₂ content, higher temperatures and longer growing seasons.

The enhancement of growth will be most pronounced in northern Finland. If the species composition of trees is managed to make optimal use of the changed conditions, 60–80% of the forests in southern Finland may consist of birch (mainly Pendula) by the year 2100. Norway spruce will decline in the south, but benefit in the north. The warming may also decrease the share of Scots pine in southern Finland (Fig. 3).

Several broadleaves will extend their distribution northwards; e.g. the oak could grow at latitude 65°N in the year 2100. However, natural extension of new tree species is usually very slow.

Milder winters may increase the risk of damaging insect pests overwintering as eggs in tree canopies. However, there might be some counteracting effects, especially through changes in the activity of natural enemies.

The forests are also susceptible to atmospheric pollution, particularly to increased tropospheric ozone. Of the common tree species in Finland, the

most sensitive to ozone damage are Pendula and Pubescent birches, although the sensitivity varies considerably according to their genetic properties.

PEATLANDS

Peatlands have a total extent of over 10 million hectares in Finland. About half of them have been drained to enhance forest growth. Peatlands provide the largest carbon storage in Finland; about 5 billion tonnes of carbon has been stored in peat. In their natural state, peatlands annually absorb about 80 grams of CO₂ per square metre.

On the other hand, peatlands convert part of their carbon dioxide to methane. A great majority of known methane emissions in Finland, up to 80%, originate from peatlands. Drained peatlands emit around 150 000 tonnes of methane per year; natural peatlands 700 000 tonnes. Industrial and agricultural methane emissions amount to 250 000 tonnes. Littoral zones of lakes may release considerable (but still unknown) amounts of methane.

The total CO₂ sink of peat of natural and drained bogs in Finland amounts to 9 million tonnes per year. In addition, the sequestration of CO₂ in the tree stands of drained bogs is about 8 million tonnes. On the other hand, the decomposition of peat on agricultural land is estimated to release 5 million tonnes of CO₂ annually.

AGRICULTURE

Under the central SILMU temperature scenario, the length of the growing season in 2050 would be extended by about 3–5 weeks relative to the present-day. A northward expansion of 250–500 km in suitability for cereal production could be anticipated (Fig. 4). The yields of adapted spring cereals will increase, new longer-season cultivars benefitting from both higher temperatures and elevated CO₂. Higher-yielding winter-sown cereals could be cultivated over much larger areas than today. There would also be potential for the successful cultivation of new crops like maize in southern Finland.

Grass yields are also expected to increase considerably due to a lengthening of the growing season and the beneficial effects of elevated CO₂. This assumes that water and nutrient limitations remain minor and that grass cultivars do not become more prone to winter damage due to reduced winter hardening under higher autumn temperatures.

Thus, the productivity of Finnish agriculture can be assumed to increase under future climate change. However, there is also an increased potential for losses due to crop pests and diseases. The range of many harmful organisms is expected to expand northwards at about the same rate as the northward shift in crop suitability. Additional generations of some species would develop successfully and new species may become established in Finland.

To illustrate, under the SILMU central scenario by 2050, potato yields are estimated to increase by some 10–50% in southern Finland and by more than 100% in northern Finland relative to the present-day. However, in the absence of plant protection, these gains could be almost wiped out by an increased incidence and severity of potato late blight. One implication of a warmer climate, therefore, is an increased need for plant protection, which may itself lead to undesirable environmental effects.

An important component of Finnish agriculture is the raising of livestock for dairy and meat production. The direct influence of climate change on animal production is likely to be small. However, climate change may bring beneficial indirect effects, including reduced feed costs due to a longer grazing season, higher yields of fodder crops and reduced dependence on supplementary feed, as well as savings in construction and heating of buildings.

INLAND WATERS

The Finnish winter may not survive in southern parts of the country; the present accumulation of seasonal snow cover is likely to be an exception in the mid-21st century. Snowmelt and rainfall may cause winter floods, warning signs of which have already been observed

Fig. 3. The estimated volume of pine, spruce and birch as a proportion of growing stock in 1990 (observed) and by 2100 under the SILMU central scenario. The birch category comprises the two common species, Pendula birch and Pubescent birch.

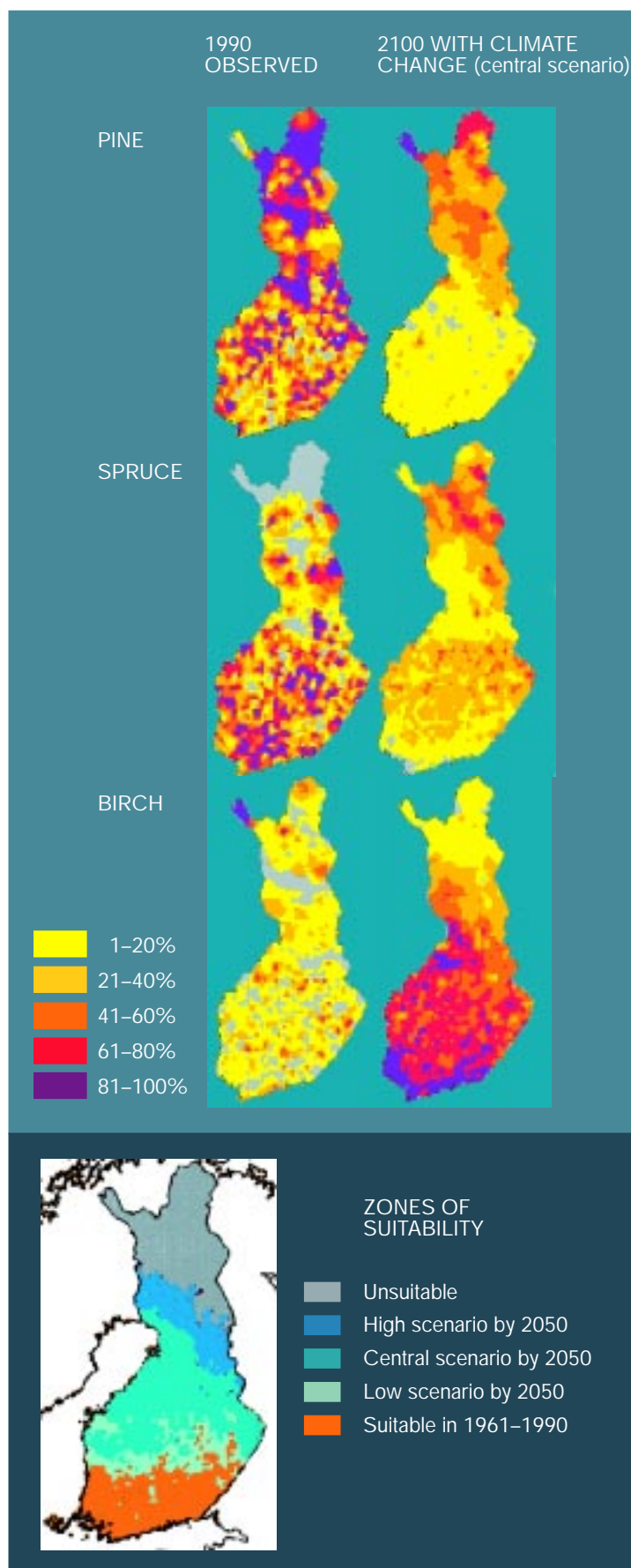
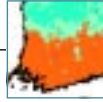


Fig. 4. The area estimated as thermally suitable for the cultivation of spring wheat at present and the extension of suitability by 2050 (all three SILMU scenarios).



in recent years. Thus the largest flood during 1989 in the River Vantaa near Helsinki occurred in February, the first in that month since records began in 1911.

In small catchments of central Finland the spring flood will attenuate and occur earlier (Fig. 5). In the large basins of the Lake District the abundant winter flows will raise the levels of major downstream lakes to flood stages in spring, for example, increasing the outflow from Lake Saimaa by 15–20% in April–May by the year 2050. The Saimaa ringed seal, the most famous endangered species in Finland, may have difficulties in finding suitable snow drifts for nesting.

In northern Finland the spring flood will also occur earlier and the peak will usually be lower than under the present climate. However, the risk of large spring floods is ever-present because winter precipitation may increase and it mainly falls as snow.

Winter floods and the lack of snow cover make the agricultural soils of southern Finland susceptible to increased leaching of nutrients. However, according to modelling results, this increase will be relatively small and can be controlled with proper protection measures.

Nitrate leaching from forest areas may increase significantly. Total nitrogen deposition in the boreal forest is large. With the high scenario of SILMU, the simulated nitrogen leaching would double before the year 2050, but the impact of enhanced forest growth can level off this increase.

The duration of ice cover in lakes will become shorter. In some of the larger lakes of southern Finland the ice cover may even disappear in midwinter during the latter half of next century. In summer the surface water temperatures will increase about as much as air temperatures.

The spring peak of phytoplankton will occur earlier and become clearly higher than today. The littoral zone is likely to be more sensitive to the effects of climate change than the pelagic ecosystem. A doubling of atmospheric CO₂ content and an increase of 2–3°C in water temperatures more than doubled the growth of some littoral macrophytes in an artificial greenhouse lake.

The habitats of many warmwater fish species are likely to expand, especially in northern Finland. Unfortunately, most of these species have little or no commercial or recreational value. Many coldwater species will suffer from warming, e.g. salmon, brown trout, arctic char and whitefish. However, the larvae and juveniles of most Finnish fish species will grow faster.

THE BALTIC

The ice season in the Finnish waters of the Baltic Sea normally lasts 5–7 months. According to the central SILMU scenario, ice cover would appear about 20 days later in 2050 and melt 10 days earlier than today. The maximum ice thickness is estimated to decrease by 20 cm. In 2100, only the Bothnian Bay will have an ice cover in a normal winter and ice thickness may be about 30 cm (Fig. 6).

The input of nitrogen to the coastal waters is expected to increase in winter. Before the onset of spring, nutrients will be transported further from the coast, with a consequent risk of eutrophication over a large area. The reduction of nitrogen loading will obviously be one of the crucial measures required to prevent harmful effects of climate change in the Baltic.

ECONOMIC IMPACTS OF CLIMATE CHANGE IN FINLAND

Because of the long time periods and many uncertainties involved, estimation of economic impacts of climate change is very difficult. In SILMU, some estimates were made on a sector by sector basis. These estimates indicated that the Finnish economy might benefit by about one per cent of GNP by 2050. However, it should be noted that detailed evaluations could not be made for all sectors, and many impacts cannot easily be valued in economic terms.

Moreover, international agreements and responsibilities as well as negative effects of climate change in other parts of the world may also bring significant costs for Finland. Thus, even if we may see no emergency coming in Finland, as a small and open economy we are very dependent on nations more vulnerable to a changing climate.

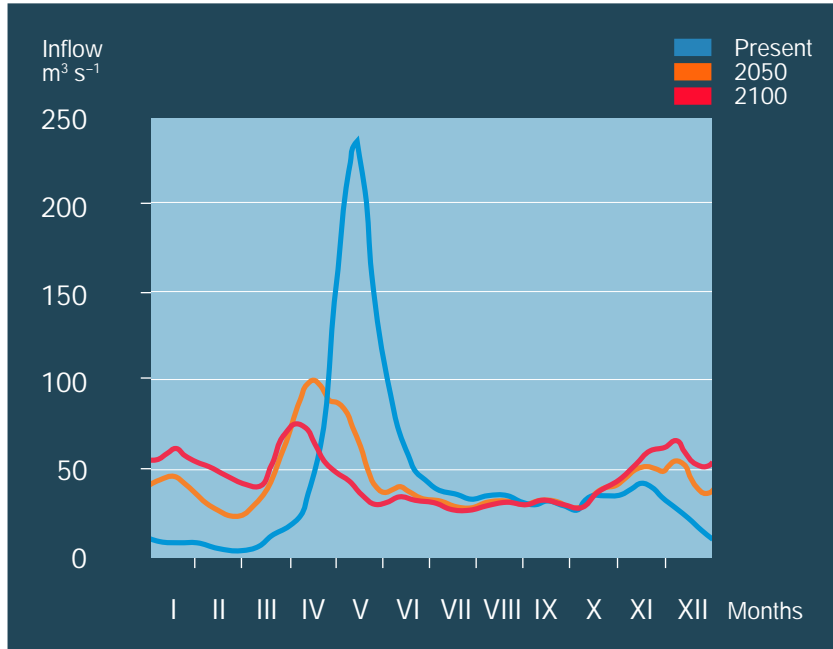


Fig. 5. The mean annual inflow hydrograph of Lake Porovesi in the northern part of the Lake District at present, in 2050 and in 2100 (central SILMU scenario).

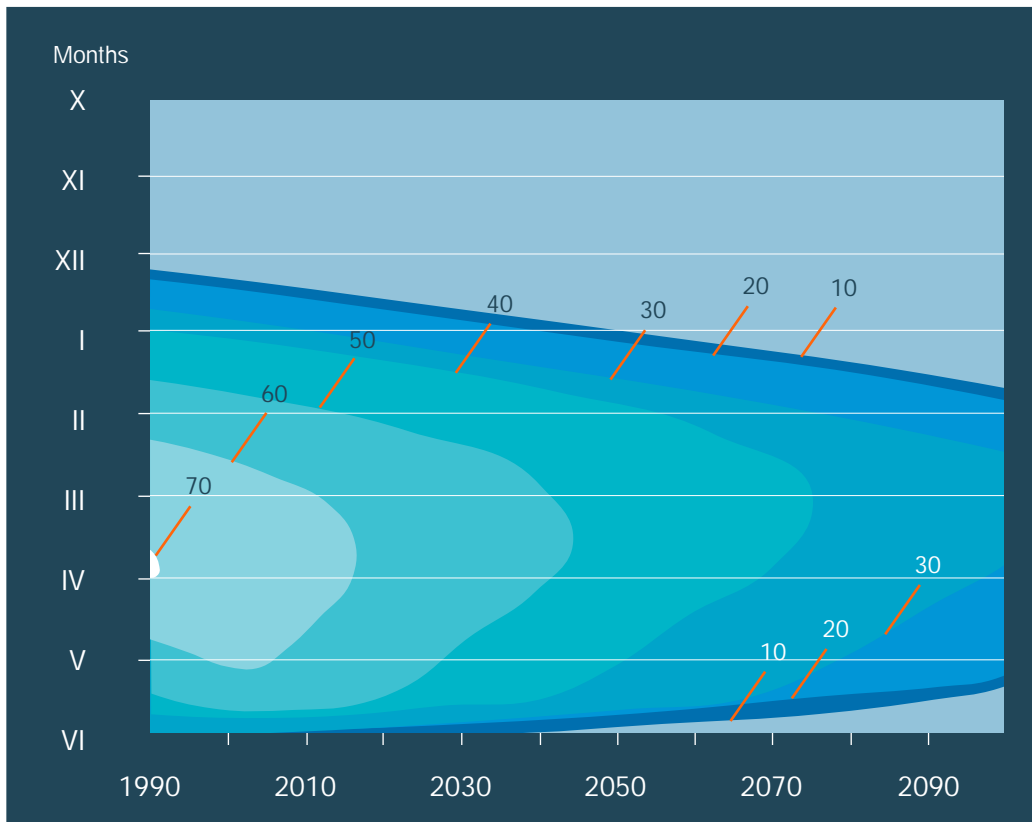


Fig. 6. Estimated average ice thickness (cm) in the Bothnian Bay (northern part of the Gulf of Bothnia) near Kemi during the period 1990–2100 (central SILMU scenario).



MITIGATION AND ADAPTATION

SOURCES AND SINKS OF GREENHOUSE GASES IN FINLAND

Finland is a signatory to the United Nations Framework Convention on Climate Change (FCCC) and among her commitments is a reduction of the Finnish contribution to global greenhouse gas emissions. A summary of the sources and sinks of three important greenhouse gases in Finland is given in Table 1.

In 1994, CO₂ emissions from the consumption of fossil fuels and peat were 57.2 million tonnes (Fig. 7). The share of oil products was 45%, coal 32%, peat 12% and gas 11%. By end-use sectors the emissions were as follows:

- industry 38%
- heating 27%
- transport 20%
- residential, services, agriculture etc. 15%.

Finland's share in global CO₂ emissions from fossil fuels was 0.25%, representing per capita emissions

of 11 tonnes. In EU countries the corresponding figure averaged 9 tonnes, in the United States almost 20 tonnes, in eastern Europe 12 tonnes and in developing countries 2 tonnes.

Wood-based fuels (black liquor, waste sludge, bark, chips, sawdust and fuelwood) released 21 Mt of carbon dioxide in 1994. The total CO₂ flow from the Finnish forests via industry and other users was 38 Mt. The release of CO₂ from forest products can occur rather quickly or it may take tens of years. About two thirds of forest products are mass and paper, one third is wood. On the basis of their carbon content, about 80% of forest products are exported.

The contribution of the Finnish forest sector to the greenhouse effect is shown in Fig. 8. The net increase of standing biomass is by far the largest sink in the balance. The largest source is methane from decomposing forest products in landfills, mainly abroad. This component will diminish in the future if the role of recycling increases.

The largest carbon storage in Finland – about sev-

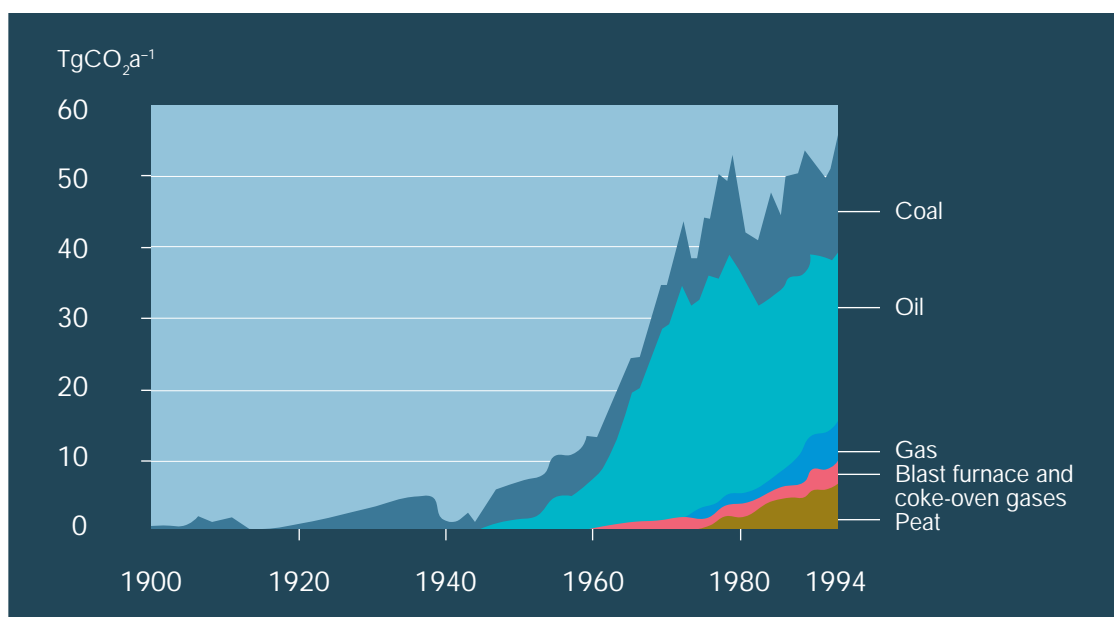


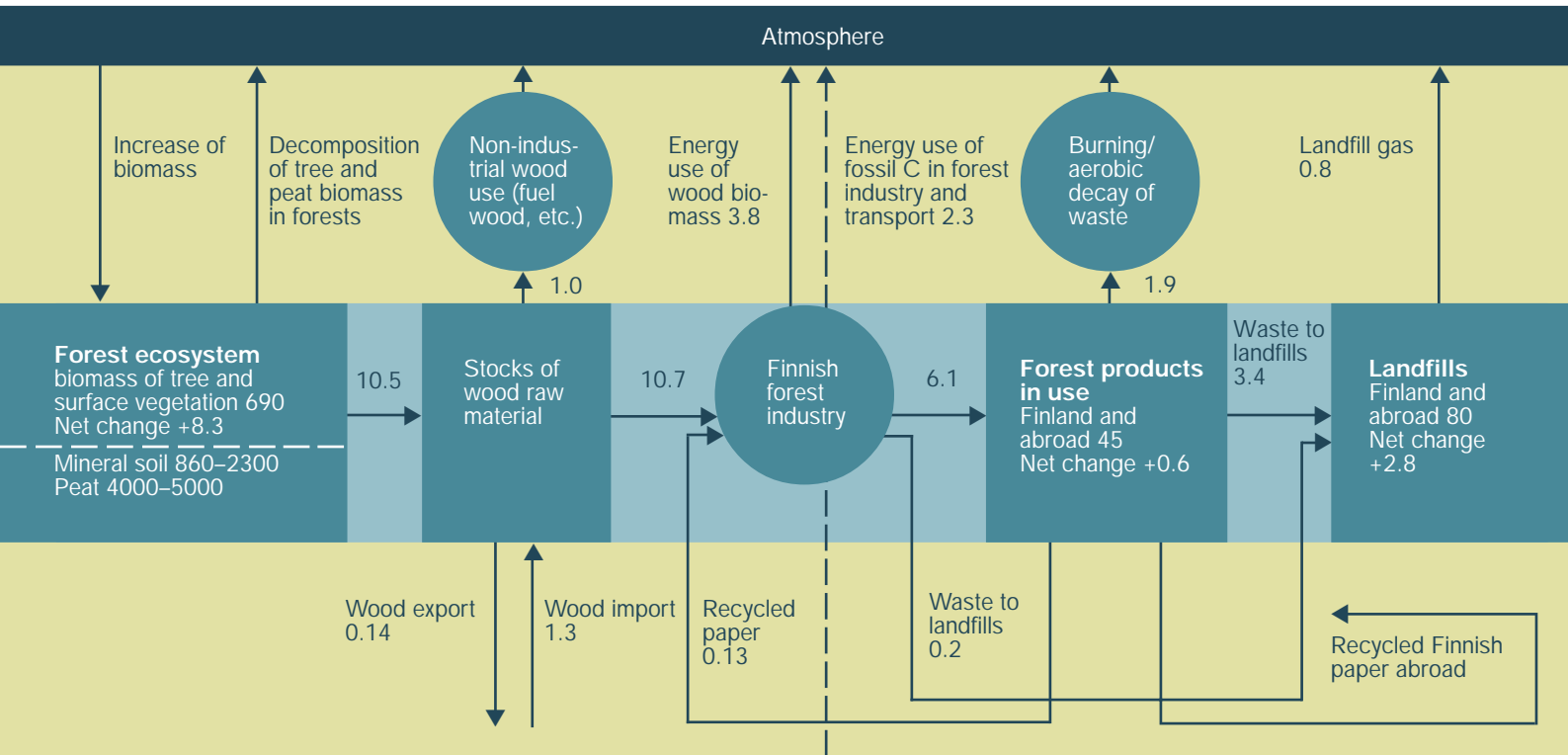
Fig. 7. CO₂ emissions in Finland, 1900–94.

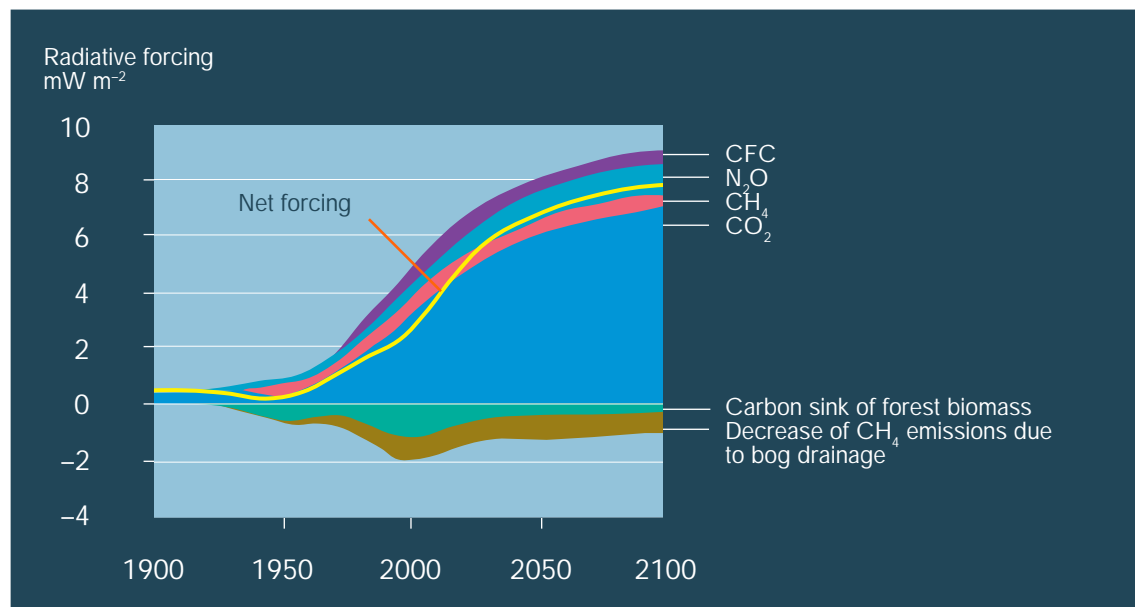
SOURCE/SINK	CO ₂	CH ₄	N ₂ O
ENERGY PRODUCTION (1994)			
fossil fuels and peat	57 200		
wood-based fuels	(21 000)		
peat production areas	500		
TOTAL ENERGY PRODUCTION	ca. 58 000 ¹	16	5
Cement industry	800		
Production of nitric acid			3
Landfills	-1 700	120	
Wastewaters		10	
AGRICULTURE			
Livestock raising		90	
Cultivation			4
Cultivated peatlands	5 000	0,8	4
FORESTS AND PEATLANDS			
growing stock	-30 000		
mineral soils		-30	3
undrained peatlands	-4 000 ²	700	0,5
drained peatlands	-5 000 ²	150	1
WATERCOURSES			
	?	?	?
TOTAL			
Sources	64 000	1 100	20
Sinks	-41 000	-30	-
Summa	ca. 23 000	ca. 1 100	ca. 20

Table 1. Estimates of major sources and sinks of carbon dioxide, methane and nitrous oxide in Finland (1000 tonnes per year).

¹CO₂ emissions from wood-based fuels not included
²Peat layer

Fig. 8. Carbon reservoirs (10⁶ tonnes) and fluxes (10⁶ tonnes C per year) of the Finnish forest sector in 1990.





en times that of tree biomass – is to be found in peat. As mentioned earlier, both natural and drained peatlands act as carbon sinks; the total carbon sink of Finnish peatlands is about 9 Mt. Landfills also form a small CO₂ sink.

The annual methane emissions of landfills are 120 000 tonnes and those of cattle raising 90 000 tonnes. These are considerably smaller than the emissions from peatlands, which were estimated to be 850 000 tonnes annually. The eutrophic littoral zones of lakes may also be an important methane source.

The radiative forcing by methane emissions in Finland is about one sixth of the forcing by fossil CO₂ emissions. The forcing of nitrous oxide is one third smaller than that of methane; the forcing by halogenated hydrocarbons lies between these two.

The direct warming effect (radiative forcing) of all greenhouse gas emissions in Finland is 0.15% of the global value. When the role of the Finnish biosphere as a sink is taken into account, our share decreases to 0.10% (Fig. 9).

REDUCING CO₂ EMISSIONS

According to the basic scenario of the Ministry of Trade and Industry, CO₂ emissions from fossil fuels and peat are expected to increase to 90 million tonnes by the year 2010. Possible measures to reduce these emissions include improved energy efficiency, a higher share of biofuels, gas or nuclear power, the import of electricity and utilization of new energy technology.

When coal is burned, the release of CO₂ amounts to 95 g MJ⁻¹. For oil the corresponding emission is 75, for gas 55 and for peat 110 g MJ⁻¹. In terms of net energy production, the emissions are considerably higher – the figures above have to be divided by the efficiency of production.

The overall efficiency of the Finnish energy production system is high in international comparison, mainly due to combined production of electricity and energy for heating. Nevertheless, a considerably higher efficiency is still possible.

The largest potential to reduce CO₂ emissions can be found in industry and heating. The largest proportional reductions are possible in those sectors in which awareness of the potential for savings is low. These include households, services, transport and small industrial enterprises.

REDUCTIONS OF OTHER GREENHOUSE GASES

There seem to be realistic possibilities to limit anthropogenic methane emissions in Finland during the coming years. Emissions from landfills and transportation will decrease owing to changes in volume and technology already decided on and partly implemented.

Decreasing the amount of landfill waste is expected to reduce emissions only after several decades, due to long time lags in decay processes. On the other hand, landfill gas recovery reduces the emissions directly. Moreover, in a warmer future

Fig. 9. Radiative forcing due to emissions of different greenhouse gases in Finland, together with the forcing of Finnish forests and peatlands. The yellow line depicts the estimated net forcing. It is assumed that the CO₂ emissions from fossil fuels are restricted to the level of 1990 by the year 2025.

climate, a slow drying of Finnish peatlands may decrease their role as a methane source.

Emissions of nitrous oxide from arable land are not expected to grow, but those from energy production and transportation will. The increasing use of fluidized bed boilers in energy production and a growing number of cars with catalytic converters will add to emissions.

The amount of free chlorine in the stratosphere from Finnish emissions will peak around 2000 and start declining slowly after that. Most of the new halogenated hydrocarbons are weaker greenhouse gases than CFCs, but their global radiative forcing may become significant without a reduction in their use or development of a recovery system. Finland will address these issues according to evolving international agreements.

THE COSTS OF GREENHOUSE GAS REDUCTIONS

CO₂ emissions can also be reduced by using economic instruments, such as a carbon tax. In SILMU, a computable general equilibrium (CGE) model was used to analyse the taxes required to reach given emission levels.

The results are very sensitive to the assumption of whether or not the basic metal industry pays the carbon tax. According to present policy this industry is not taxed because it is not classified as an energy use.

In order to reduce CO₂ emissions to the level of

1990 by the year 2010, a carbon tax which also covers the metal industry should amount to 300 FIM/tonnes of CO₂. If the metal industry is left out, the required tax level would have to be doubled. The resulting decrease in GDP due to a carbon tax would be 0.6% in the former case and 1.0% in the latter case.

In these analyses, the target was to reduce CO₂ emissions from fossil fuel burning. If instead the target is to reduce national net CO₂ emissions, an increase in the carbon sink of forests can be included in the model. According to the preliminary results, this would decrease the national costs of reducing CO₂ emissions. However, this alternative may be unprofitable to the forest industry, because it tends to decrease the supply of wood.

According to the double dividend hypothesis, it has been argued that environmental taxes are not only environmentally efficient but also efficient from an economic point of view. As usual in the CGE models, environmental benefits were excluded. CO₂ tax revenues were used to reduce labour taxes and indirect taxes or they were returned as lump sum transfers. In all cases GNP was reduced 1.2–1.8% and the double dividend hypothesis was rejected. However, tax replacement could partly compensate the negative effects of CO₂ tax.



ADAPTATION

Some possible means of adaptation to climate change in Finland are presented in Table 2.

The Finnish economy is closely dependent on the forestry sector. Due to the long time scales involved, the forest might be more sensitive to climate change than other ecosystems or agriculture. Over the next few decades warming could enhance forest growth. However, Finland should also be prepared for an increased risk of forest damage.

The adaptation of agriculture to climate change depends – in addition to the farmer – on technological progress and agricultural policies at the regional, national and international level. One challenge will be the development of new crop varieties which are able to exploit the future conditions optimally. Maintaining soil properties sustainably for crop production might also require considerable efforts in the future.

As to water resources, changes in hydrological regimes and leaching should be anticipated. An in-

crease of winter flows can also alter considerably the conditions for hydro power production.

CLIMATE, POLITICS AND THE WAY OF LIFE

Finnish opinion formers (politicians, journalists, cultural personalities etc.) and the general public were interviewed during SILMU. The possibility of climate change was regarded by both groups as a serious global risk in the future. Opinion formers identified climate change as the most serious environmental threat, whereas the public placed it behind nuclear energy and air and water pollution.

The most serious consequences of climate change were thought likely to occur elsewhere than in Finland. Most interviewees believed that global warming could lead to e.g. desertification and sea level rise. The number of environmental refugees was assumed to increase.

Who is guilty of climate change? This was not explicitly specified by the interviewees, but the issue

Table 2.
Some means
of adaptation
to climate
change in
Finland.

FOREST	<ul style="list-style-type: none"> Preparedness for increased damage Preparedness for changes in soil moisture and leaching Maintenance of biodiversity Changes in the proportions of tree species Introduction of new species Improved risk control in forestry
AGRICULTURE	<ul style="list-style-type: none"> Plant breeding, changes in crop species and varieties Timing of cultivation practices Maintenance and improvement of soil properties Lengthening of the grazing season Modified and improved pest/disease control
WATERCOURSES	<ul style="list-style-type: none"> Preparedness for changes in precipitation and runoff Preparedness for changes in leaching and eutrophication
ENERGY SECTOR	<ul style="list-style-type: none"> Preparedness for changes in hydropower production



was connected to the main stream of industrialization and to the modern way of living, which consumes a lot of energy.

From the standpoint of the public in Finland, climate change is an integrated part of the overall ecological issue in the modern world. People anticipate that the pursuit of material well-being will lead to an accelerating future decline in the quality of life, unless strong protective measures are applied.

There was a broad consensus for the need to work together to reduce environmental hazards. International climate agreements were supported. The public also claimed to be more actively engaged in everyday actions to protect the environment than the opinion formers assume.

WHAT COMES AFTER SILMU?

The SILMU programme has considerably increased our knowledge on important climate change issues in Finland. Many individual research projects within SILMU also worked in co-operation with scientists in other countries and with international research programmes on global change, especially with the World Climate Research Programme and the International Geosphere-Biosphere Programme.

The results and findings of SILMU should be regarded as initial estimates. Inevitably they encompass

numerous uncertainties. In many research projects, only the central climate change scenario has been used. Even with all three scenarios, many models may ignore important factors.

Despite the many international connections, SILMU was almost exclusively a nationally constrained study. Likely future events in the outside world were largely ignored. Even at national level SILMU may not have succeeded in focusing enough on the values of the natural Finnish environment (e.g. forest ecosystems, the Finnish winter, landscape, biodiversity, national parks and nature reserves).

An international team evaluated SILMU in August 1996. As part of the evaluation, SILMU researchers were asked to list priority topics for continued studies. These included:

- Special features of the climate in northern Europe (the influence of the Atlantic Ocean; ozone depletion)
- Boreal and subarctic ecosystems; the role of the biosphere in greenhouse gas balances
- Leaching of nutrients and its impact on aquatic ecosystems
- Economic and social implications of climate change; strategies of mitigation and adaptation
- Effects of climate change on biodiversity in Finnish ecosystems
- Identification of critical thresholds of climate change in Finland

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