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FINSKEN: a framework for developing consistent global change scenarios for Finland in the 21st century

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This paper presents the rationale, methodology and results of the three-year FINSKEN project to develop global change scenarios for Finland in the 21st century. Scenario consistency was pursued by relating all scenarios to the same global driving factors of environmental change specified by the IPCC. Scenarios were constructed of socio-economic development, climate, sea level, surface ozone exposure, and sulphur and nitrogen deposition. Both empirical and modelling approaches were used to develop scenarios. Linkages between scenario types were examined to improve scenario integration. Stakeholder dialogue was encouraged through a questionnaire survey, two project seminars, and face-to-face interviews. Two types of future world are described: a consumer-driven "A-world" and a community-minded "B-world". In the A-world there is strong economic growth in Finland accompanied by rapid increases in CO_2 concentration, increased ozone pollution and nitrogen deposition, rapid climate warming, increased precipitation and a possible reversal from falling to rising sea levels. The B-world shows lower economic growth than the A-world, and less rapid increases in CO_2 concentration, temperature and precipitation. After initial increases, ozone pollution and deposition are unlikely to exceed present levels and will probably be much lower by the end of the century. Sea levels in southern Finland either stabilise or continue to fall.

Introduction

The role of human activities in altering the natural environment is undisputed (United Nations 2002). Pollution of the atmosphere, soil, inland waters and oceans combined with widespread changes in land use have contributed to environmental problems such as acid rain, eutrophication, soil impoverishment, climate change and stratospheric ozone depletion. Environmental change has become known as *global change*, because it affects all areas of the globe and because it touches upon all aspects of the relationship between human development and the natural world.

Finland is also affected by global change, as indicated by long-term monitoring of the atmosphere, soil, vegetation and waters (e.g. Wahlström *et al*. 1996, Johansson *et al*. 2004, Jylhä *et al*. 2004, Laurila *et al*. 2004). While some of these changes are natural in origin, a significant proportion can be attributed to worldwide human activities, such as fossil fuel combustion, land clearance and intensive agriculture. The underlying driving factors responsible for these trends are population growth, economic development and the exploitation of natural resources.

In order to be able to estimate the future implications of global change, it is necessary to project these socio-economic driving factors of change into the future. However, there are formidable uncertainties associated with estimates of future human behaviour, so precise forecasts of future trends are not possible. Rather than predictions (to which measures of likelihood can be attached), an alternative approach is to construct *scenarios*. A scenario can be defined as "a coherent, internally consistent and plausible description of a possible future state of the world" (IPCC 1994). Scenarios enable analysts to investigate uncertainties in future projections and to examine "what if" type questions about the future environment. Different types of scenarios and their potential roles are further elaborated below.

This paper presents the rationale, methodology and general results of a three-year project to develop global change scenarios for Finland in the 21st century. The project, FINSKEN (Developing Consistent Global Change Scenarios for Finland), is part of the Finnish Global Change Research Programme (FIGARE). Detailed results of the project are presented in other papers in this volume (Kaivo-oja *et al.* 2004, Jylhä *et al.* 2004, Johansson *et al.* 2004, Laurila *et al.* 2004, Syri *et al.* 2004).

Types of scenario and their potential role in Finland

Global change scenarios serve a wide range of roles for research, education and decision making. A broad distinction is sometimes made between exploratory (or descriptive) scenarios, which describe how the future might unfold according to known processes of change or as extrapolations of past trends (sometimes referred to as "business-as-usual" scenarios), and normative (or prescriptive) scenarios, which portray prespecified future conditions, either desired or to be avoided (Nakićenović *et al.* 2000). In practice many scenarios embrace aspects of both approaches.

A number of uses for scenarios in policy-orientated environmental assessments are identified by Alcamo (2001), in particular to:

— provide a picture of future alternative states of the environment,
— raise awareness about the future connection between different environmental problems,
— illustrate how alternative policy pathways can achieve an environmental target,
— combine qualitative and quantitative information about the future evolution of an environmental problem,
— identify the robustness of environmental policies under different future conditions,
— help stakeholders, policymakers and experts to account for the large time and space scales of a problem,
— help raise awareness of new or intensifying environmental problems.

In Finland, global change scenarios are both of scientific and policy importance. Scientists require projections for assessing the likely consequences for natural ecosystems, for economic activities like forestry, energy production, transportation, and agriculture, and for human health and welfare. Moreover, characterisations of plausible alternative future socio-economic conditions in Finland provide useful information about the ability to adapt to global change. Projections are also valuable for policy makers who must decide appropriate responses at local, national and international levels. In addition, they can inform and educate the general public about issues that impinge on everyday life.

Previous work on scenario development

In Finland, scenarios of different types have been applied to contrasting situations (Bärlund and Carter 2002). Some scenarios are largely normative in design — for instance, the National Forest Programme for 2010 sets its goals according to a "vision of a sustainable forest management and protection — *the preferred state of affairs in 2010* ..." (Ministry of Agriculture and Forestry 1999: p. 5). Other scenarios are more descriptive, such as the national emissions scenarios for Finland up to 2020, estimated assuming alternative energy policies (Ministry of Trade and Industry 2001). Yet others combine both normative and descriptive elements, such as the scenarios of organic farming in Finland by 2010 developed by Kröger (2001), which differentiate between a most desirable future (“organic Finland”), a probable future (“business-as-usual”) and a worst case scenario (“techno-Finland”).

Most scenarios are developed to serve specific objectives, for example strategic planning (e.g. YTV 1997, Ministry of Agriculture and Forestry 1999, Ministry of Trade and Industry 2001), long-term impact and risk assessment (e.g. Carter *et al.* 1996, Melanen and Ekqvist 1997), and the assessment of national targets and compliance under international agreements (e.g. Hilden *et al.* 2001). However, none of the above-mentioned scenarios are especially useful if a broad and consistent perspective on future global change is required, because they:

— are limited in scope to the subject areas under study,
— are unlikely to be consistent with scenarios developed for other purposes,
— may have neglected some important aspects of environmental change,
— are of varying quality,
— were developed assuming different baselines and different time horizons.

FINSKEN: towards integration of global change scenarios

Aside from not being consistent, the case-specific treatment of environmental change scenarios in Finland also fails to account for important dependencies between global changes. For example, projections of future acidification and eutrophication in Finland (e.g. Syri *et al.* 1999) make use of scenarios of sulphur, nitrogen and ammonia emissions developed according to international conventions (UN/ECE 1999) and national air pollution policies (Melanen and Ekqvist 1997). In contrast, impacts of future climate change in Finland (e.g. Kuusisto *et al.* 1996) make use of climate projections (Carter *et al.* 1996) assuming global greenhouse gas and aerosol emissions scenarios generated independently by the Intergovernmental Panel on Climate Change (Leggett *et al.* 1992). However, the emissions causing these different environmental changes largely originate from the same sources (i.e., fossil fuel combustion).

Furthermore, changes in one environmental factor can often affect changes in another. For example, changes in temperature, precipitation and wind may affect patterns of acid deposition (Pitovranov 1988, Posch *et al.* 1996). In addition, the trans-national or global scope of environmental changes demands that scenarios be consistent with projections widely accepted internationally. Finally, from a policy perspective, it is becoming increasingly clear that policies to address one type of environmental change can have ancillary effects on other types of change (for example, reducing emissions to tackle air pollution can affect greenhouse gas emissions and hence climate). An integrated approach has therefore become a policy imperative (RIVM 2001).

Recognising these interdependencies and policy needs, and following some initial attempts at integration across global change scenarios (e.g. Forsius *et al.* 1997, Syri and Karvosenoja 2001), the FINSKEN project represents a concerted effort to design scenarios for Finland that are mutually consistent and which extend beyond the time horizons adopted in many previous exercises. The following scenarios have been developed:

— socio-economic and technological scenarios (Kaivo-oja *et al.* 2004),
— climate scenarios (Jylhä *et al.* 2004),
— sea level scenarios (Johannson *et al.* 2004),
— tropospheric ozone scenarios (Laurila *et al.* 2004).
— sulphur and nitrogen deposition scenarios (Syri *et al.* 2004),

The remainder of this paper describes the overall methodology applied in developing the FINSKEN scenarios (next section), provides a synopsis of the main results and concludes by discussing the potential application of the scenarios by end-users and by suggesting useful follow-up activities to update and extend the scenarios.

Methods

The relationships between key elements of the FINSKEN project are illustrated in Fig. 1. A key

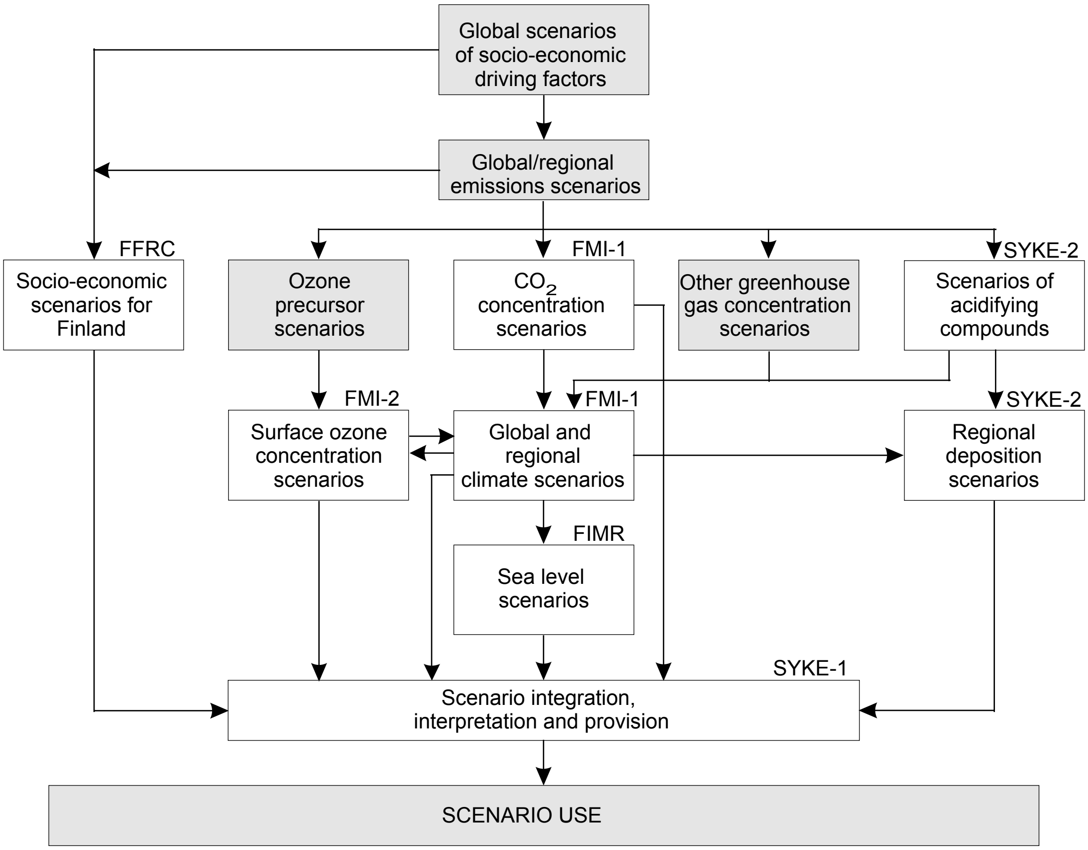

Fig. 1. Main elements of the FINSKEN project and their linkages. Elements in shaded boxes were not treated explicitly in the project. Acronyms refer to the four partner institutes.

objective of the project was to develop scenarios that are mutually consistent. In order to achieve this, all scenarios developed in the project can be traced back to a common set of global driving factors (top of Fig. 1). These global drivers are outlined in this section, followed by a description of the main approaches used in selecting, constructing and disseminating the scenarios.

Common global driving factors: the IPCC SRES storylines

The common drivers of environmental change applied in FINSKEN are the global scenarios reported in the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES — Nakićenović *et al.* 2000). The IPCC defined four narrative storylines, labelled A1, A2, B1 and B2, describing the relationships between the forces driving greenhouse gas and aerosol emissions and their evolution during the 21st century for large world regions (macro-regions) and globally (Fig. 2). Each storyline represents different demographic, social, economic, technological, and environmental developments that diverge in increasingly irreversible ways. The SRES macro-regions are listed in a footnote to Table 1 (*see* below).

The four storylines are discriminated by reference to two dimensions of future development represented on perpendicular axes in Fig. 2. One dimension describes social and economic values (vertical axis). This ranges from consumer-driven values that emphasise personal freedom and economic development at one extreme (A1 and A2 storylines), to community-orientated values that stress concern for the common good, including the environment, at the other extreme (B1 and B2 storylines).

The second dimension describes structures of governance, reflecting economic and political power and decision-making (horizontal axis in Fig. 2). This extends from an interdependent, globalised structure of decision-making at one extreme (A1 and B1 storylines) to an autonomous, localised structure of decision-making at the other (A2 and B2 storylines).

The four storylines are described below (Nakićenović *et al*. 2000):

- A1 storyline and scenario family: a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and rapid introduction of new and more efficient technologies.
- A2 storyline and scenario family: a very heterogeneous world with continuously increasing global population and regionally oriented economic growth that is more fragmented and slower than in other storylines.
- B1 storyline and scenario family: a convergent world with the same global population as in the A1 storyline but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies.
- B2 storyline and scenario family: a world in which the emphasis is on local solutions to economic, social, and environmental sustainability, with continuously increasing population (lower than A2) and intermediate economic development.

After determining the basic features of each of the four storylines, including quantitative projections of major driving variables such as population and economic development taken from reputable international sources (e.g. United Nations, World Bank and IIASA), the storylines were then fully quantified using integrated assessment models, resulting in families of scenarios for each storyline. In all 40 scenarios were developed by six modelling teams. All are considered equally valid, with no assigned probabilities of occurrence. Six groups of scenarios were drawn from the four families: one group each in

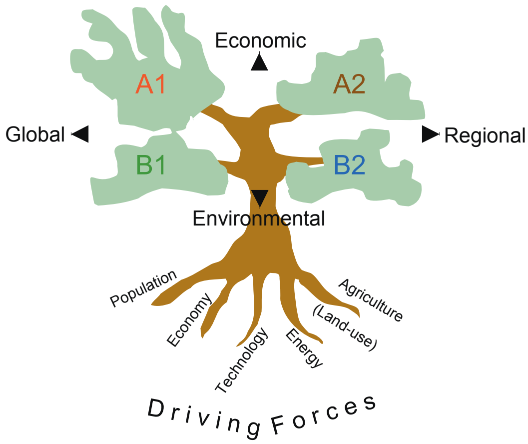

Fig. 2. The four IPCC SRES scenario storylines (after Nakićenović *et al.* 2000).

the A2, B1 and B2 families, and three groups in the A1 family, characterising alternative developments of energy technologies: A1FI (fossil intensive), A1T (predominantly non-fossil) and A1B (balanced across energy sources). Illustrative scenarios were selected by the IPCC to represent each of the six scenario groups. Some attributes of the global illustrative scenarios are shown in Table 1.

Within each family and group some scenarios share harmonised assumptions on global population, gross world product and final energy, while other scenarios explore uncertainties in driving forces beyond those of the harmonised scenarios. Figure 3 illustrates the SRES scenario structure with, on the bottom line, a list of the scenarios actually applied in FINSKEN. Four illustrative scenarios, one for each scenario family, were released in draft form as "marker scenarios" in 1998 so that they could be applied in global climate model simulations in preparation for the IPCC Third Assessment Report (TAR). These are also indicated in Fig. 3, as they form the basis for some of the FINSKEN scenarios reported in this paper.

An important feature of the SRES emissions scenarios is that they do not include policies explicitly designed to account for climate change. Rather, they should be regarded as baseline, non-intervention scenarios. The IPCC has also begun to consider scenarios that are designed to mitigate climate change, which they term "post-SRES" scenarios (Morita *et al*. 2001).

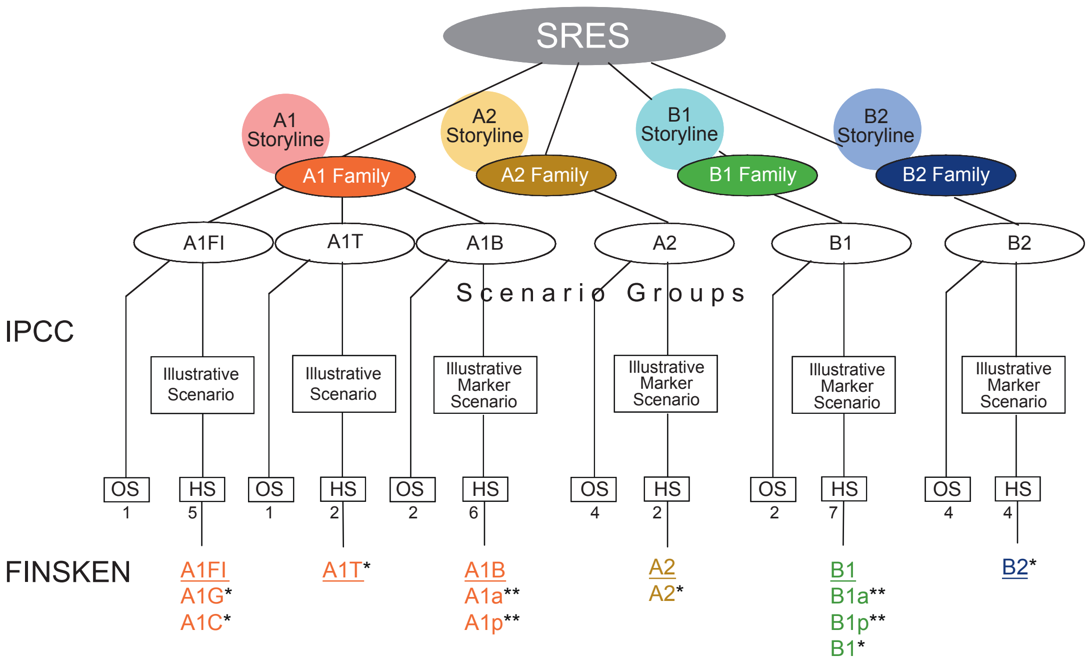

Fig. 3. The general SRES framework and scenarios selected for FINSKEN (modified from Nakićenović *et al.* 2000). HS are scenarios that share harmonised assumptions about population, gross domestic product and final energy; OS are other scenarios. Numbers of scenarios are also shown. FINSKEN scenarios underlined are the six SRES illustrative scenarios; * indicates scenario from the MESSAGE model; ** denotes air pollution policy scenario developed for the AIR-CLIM project (Mayerhofer *et al.* 2002).

Table 1. Some features of the 6 IPCC SRES illustrative scenarios at global scale* for 2020, 2050 and 2100 compared with respective values for 1990 (data from Nakićenović *et al.* 2000).

Storyline/family		A1			A2	B1	B2
Illustrative scenario	1990	A1FI	A1B	A1T	A2	B1	B2
Population (billion)	5.3						
2020		7.6	7.5	7.6	8.2	7.6	7.6
2050		8.7	8.7	8.7	11.3	8.7	9.3
2100		7.1	7.1	7.0	15.1	7.0	10.4
World GDP (10^{12} 1990 US$/yr)	21						
2020		53	56	57	41	53	51
2050		164	181	187	82	136	110
2100		525	529	550	243	328	235
CO_2 emissions, fossil fuels (GtC/yr)	6.0						
2020		11.2	12.1	10.0	11.0	10.0	9.0
2050		23.1	16.0	12.3	16.5	11.7	11.2
2100		30.3	13.1	4.3	28.9	5.2	13.8
Sulfur dioxide emissions (MtS/yr)	70.9						
2020		87	100	60	100	75	61
2050		81	64	40	105	69	56
2100		40	28	20	60	25	48

* Scenarios were also produced for four mega-regions: — OECD90: members of the Organization of Economic Co-operation and Development in 1990; — REF: countries in Eastern Europe and the former Soviet Union undergoing economic reform; — ASIA: all developing countries in Asia; — ALM: rest of the world, including all developing countries in Africa, Latin America and the Middle East.

These start with the SRES reference pathways but then depart from them in order to achieve certain mitigation targets (e.g. stabilisation of atmospheric CO_2 concentration at a prespecified level). Interestingly, although they are non-intervention scenarios, some of the SRES scenarios closely resemble mitigation scenarios (e.g. the B1 illustrative scenario — cf. Table 1) because they assume policies that promote emissons reduction for other reasons than climate. In FINSKEN, explicit climate policy scenarios were only considered in the evaluation of sulphur and nitrogen deposition (Syri *et al*. 2004), using estimates of likely Finnish emissions under the Kyoto Protocol (Hildén *et al*. 2001) and possible European-wide emissions to achieve stabilisation of CO_2 at 450 and 550 ppm obtained from the AIR-CLIM project (Mayerhofer *et al*. 2002). These scenarios were included here, in addition to the standard non-intervention SRES scenarios, because emissions policies for air pollution control in Europe are increasingly being integrated in government planning with emissions policies for climate change (RIVM 2001).

Choice of scenario types

Some of the scenarios developed for FINSKEN cover issues that have been the focus of national and international attention among researchers and policy makers in recent decades. Air pollution, acidification of soils and eutrophication of lakes were studied in detail during the HAPRO research programme (Kauppi *et al*. 1990), and climate change and its impacts were the focus of the five year Finnish Research Programme on Climate Change — SILMU (Kuusisto *et al*. 1996) and are also components of the recent Finnish Global Change Research Programme (FIGARE — Käyhkö and Talve 2002). These issues have particular policy relevance in connection with international agreements such as the Convention on Long-Range Transboundary Air Pollution to Abate Acidification, Eutrophication and Ground-Level Ozone, the UN Framework Convention on Climate Change and related Kyoto Protocol, and the United Nations Convention on Biological Diversity. As well as offering an opportunity to update existing scenarios of climate and air pollution, FINSKEN also represents a first attempt in Finland to integrate scenario development between the two issues. Moreover, the conventional decade-scale time horizon of air pollution scenarios has been extended to cover the whole century.

Other FINSKEN scenarios address relatively new or neglected issues. Sea-level rise has historically been regarded as a "non-issue" in Finland, where the land is still rising following the disappearance of ice after the last glacial period (Lisitzin 1964, Vermeer *et al*. 1988). However, this trend seems to have slowed during the 20th century in the Gulf of Finland (Johansson *et al*. 2001), and in the light of projected global sea-level rise due to global warming, a re-assessment of projected sea level on the Finnish coast is likely to be of interest for scientists and for coastal managers alike.

Socio-economic and technological scenarios are increasingly being recognised as of fundamental importance in determining the capacity of society to respond to environmental change through mitigation (Morita *et al*. 2001) or adaptation (Tol 1998, Carter *et al*. 2001). In Finland, although socio-economic projections over time horizons of up to one or two decades into the future are commonly required for strategic planning by government and the private sector, projections over longer time horizons have rarely been attempted, due to the very high uncertainties involved. This contrasts with efforts in other regions such as the United Kingdom (UK Climate Impacts Programme 2000), the United States (Parson *et al*. 2002) and the European Union (Jordan *et al*. 2000). Some of these scenario-building exercises have involved large research teams and active stakeholder participation. In view of the limited resources available in this project, the scenarios developed in FINSKEN should be regarded as exploratory and highly preliminary.

Clearly, the FINSKEN scenarios represent only a subset of global change scenarios that might have been chosen. Additional scenarios have been developed in parallel by other research groups (e.g. scenarios of stratospheric ozone and ultraviolet radiation by Taalas *et al*. 2002), but numerous other scenario types remain to be examined (e.g. scenarios of water use, availability and quality, soil degradation, land use change and small particles in the atmosphere).

Translating the SRES storylines into national scenarios

The bulk of the analytical work in the project has involved interpreting the SRES storylines at national and local scale in Finland. Two main approaches have been adopted to achieve this (Table 2): (i) empirical analysis and (ii) model analysis and application.

Empirical analysis

All groups conducted a literature review to familiarise themselves with previous work on scenario development in their field, both within Finland and elsewhere. One issue confronting several groups was the need to harmonise the SRES emissions scenarios with other scenarios already applied. For example, in projecting ozone concentrations and sulphur and nitrogen deposition in Finland, researchers have conventionally applied scenarios reflecting pollution abatement policies. However, the SRES emissions scenarios were developed to consider a range of emissions scenarios as they might affect climate change without always accounting for recent emissions policy. Thus, there has been a need to apply expert judgement based on the existing literature and emissions data, to reconcile sometimes contradictory trends in the SRES and policy scenarios (Syri *et al*. 2004, Laurila *et al*. 2004). Scenarios of forest land cover in Finland, developed in conjunction with the EC ATEAM project, were based on a combination of estimates of demand for forest products in Europe under different SRES scenarios from an integrated assessment model (IMAGE Team 2001), information on current forest land use policy taken from the literature, and subjective interpretation of other pressures on forest land use under the SRES scenarios (Kankaanpää and Carter 2004).

A second form of empirical analysis is the examination of historical observations of environmental change. Recent trends in ozone concentrations, various climatic variables, and tide gauge measurements of sea level are all reported in FINSKEN. Moreover, historical data on socio-economic and welfare indicators such as population, income, employment and energy are essential inputs to the International Futures (IFs) model applied in developing socio-economic scenarios (Kaivo-oja *et al*. 2004).

A third application of empirical analysis in FINSKEN has been the selection of appropriate scenarios from the available empirical and model-based sources. Where possible, all groups have attempted to provide scenarios from each of the four SRES storylines. In some cases, they have been able to provide scenario alternatives or uncertainty ranges for each storyline. On the other hand, in order to avoid a proliferation of projections, some groups have devised methods of ensemble averaging or have excluded scenarios regarded as highly implausible. These procedures rely heavily on expert judgement, including input from potential stakeholders.

Model analysis and application

A large portion of the scenario development work in FINSKEN has involved the analysis of results from simulations with mathematical models of varying complexity or the direct application of models (Table 2). The most influential model outputs, used to develop four different types of scenarios, were from atmosphere-ocean general circulation models (AOGCMs). These are numerical models of the climate system that are capable of providing regional estimates of climate in response to given changes in greenhouse gas and aerosol concentrations. A new set of AOGCM simulations based on the SRES emissions scenarios was conducted at research centres around the world in preparation for the IPCC TAR and has recently been made available to researchers via the IPCC Data Distribution Centre (Parry 2002). Estimates from AOGCMs of changes in temperature and precipitation (as well as a number of other variables) over Finland form the basis of the climate scenarios presented in FINSKEN (Jylhä *et al*. 2004), which supersede the climate scenarios developed for the SILMU programme (Carter *et al*. 1996). In addition, estimates of climate change over the northern

Table 2. Sources of data and methods applied at different scales in developing and disseminating FINSKEN scenarios.

Data and methods	Scale of analysis	Scenarios				
		Socio-economic	Climate/CO_2	Sea level	S/N deposition	Ozone exposure
Global/regional driving factors (exogenous)						
SRES storylines and socio-economic drivers[1]	Global/Finland	X				
SRES emissions scenarios[2]	Global/Regional	X			X	X
Emissions control scenarios[3,4]	Europe/Finland				X	X
Empirical analysis						
Observations and monitoring[4,5,6,7]	Finland	X	X	X		X
Literature survey/expert judgement[3,4,5,6,7]	Europe	X	X	X	X	X
Questionnaire survey[8]	Finland	X	X	X	X	X
Stakeholder interviews[5]	Finland	X				
Model outputs used in FINSKEN						
Atmosphere-ocean general circulation models[9]	Global/Regional		X	X	X	X
Global atmospheric chemistry models[10]	Global/Regional					X
Bern-CC TAR carbon cycle model[11]	Global		X			
Upwelling-diffusion energy balance climate model[12]	Global		X	X		
Thermal expansion and ice melt model[13]	Global			X		
EMEP acid deposition model[3]	Europe				X	
Regional climate models[14]	N. Europe		X			
Models applied in FINSKEN						
International Futures model[15]	Global/Finland	X				
EMEP photochemical model[16]	Europe					X
DAIQUIRI regional deposition model[17]	Finland				X	
AOT40 ozone exposure index[18]	Finland					X
Land uplift coefficients[19]	Local			X		
Dissemination activities						
Seminars[20]	Finland	X	X	X	X	X
Web[21]	Finland/International	X	X	X	X	X
Reports[22]	Finland/International	X	X	X	X	X

[1] Nakićenović *et al.* (2000), Gaffin *et al.* (2004); [2] AIR-CLIM project (Mayerhofer *et al.* 2002); [3] Syri *et al.* (2004); [4] Laurila *et al.* (2004); [5] Kaivo-oja *et al.* (2004); [6] Jylhä *et al.* (2004); [7] Johansson *et al.* (2004); [8] Bärlund and Carter (2002); [9] IPCC Data Distribution Centre (and *see* Parry 2002); [10] Prather *et al.* (2001); [11] Prentice *et al.* (2001), [12] Cubasch *et al.* (2001); [13] Church *et al.* (2001); [14] Rummukainen *et al.* (2001); [15] Hughes (1999); [16] Simpson (1992); [17] Syri *et al.* (1998); Kangas and Syri (2002); [18] Tuovinen *et al.* (2002); [19] Kahma *et al.* (2002); [20] Carter (2001); [21] http://www.finessi.info/finsken; [22] Carter *et al.* (2002).

European region dynamically downscaled from AOGCM runs using the Rossby Centre regional climate model (Rummukainen *et al*. 2001), have also been analysed in FINSKEN.

AOGCM outputs have also served an important integrating role in FINSKEN. They have been applied in estimating the joint effects of climate change and emissions on sulphur and nitrogen deposition (Syri *et al*. 2004), taking results from the EC AIR-CLIM project which used AOGCM results as inputs to the EMEP acid deposition model (Mayerhofer *et al*. 2002). Scenarios of temperature change based on AOGCM outputs scaled to represent the SRES emissions scenarios over Europe in the EC ACACIA project (Hulme and Carter 2000) were also applied directly with SRES emissions to the EMEP photochemical model to estimate the effects of temperature and emissions on ozone exposure (Laurila *et al*. 2004). Finally, the AOGCMs used in developing the FINSKEN climate scenarios were also examined for indications of possible atmospheric circulation changes over the North Atlantic, which would be of importance for sea level scenarios on the Finnish coast (Johansson *et al*. 2004).

Other models have also occupied a central role in the development of individual scenario types. For example, the International Futures (IFs) model, an integrated assessment model developed in the United States (Hughes 1999), has been applied at national scale to analyse the historical relationships between different demographic, social, economic and technological factors in Finland (Kaivo-oja *et al*. 2004). The DAIQUIRI regional deposition model was used to integrate estimates of long range transport from the EMEP acid deposition model with local Finnish emissions (Syri *et al*. 2004). An ozone exposure index modified in Finland was used to evaluate the exposure of agricultural crops and forests to ozone concentrations under different scenarios (Laurila *et al*. 2004).

Stakeholder involvement

Ultimately, judgements on the plausibility, applicability and usefulness of global change scenarios are made by those persons or institutions applying them in research, policy-making, planning or as public information. Three stages of stakeholder involvement in scenario development have been followed in FINSKEN (Bärlund and Carter 2002): (i) stakeholder engagement and problem definition, (ii) scenario formulation and stakeholder dialogue, and (iii) scenario refinement and selection.

1. *Stakeholder engagement and problem definition* entails the identification of important actors who may have a stake in the global changes to be projected and who may be able to contribute their expertise in selecting and developing scenarios that are relevant for their needs. Techniques applied for this purpose in previous Finnish studies include the use of a questionnaire (e.g. Tirkkonen and Wilenius 1996) or a workshop (Carter *et al*. 1993). For FINSKEN, initial contact with potential stakeholders was established by means of a questionnaire survey in early 2000. This was sent out to over 600 persons, representing government ministries, regional authorities, public utilities, private companies, non-profit-making associations, research institutes and universities (Bärlund and Carter 2002). The main methods used to identify such persons included personal contacts, examination of mailing lists for research programmes and conferences, and an extensive search on the Internet. To encourage a satisfactory response rate, the questionnaire was limited to a set of nine questions that aimed to monitor respondents' interest in the five scenario types included in the project (*see* Introduction) and to report their possible need for additional scenarios or scenario attributes.
2. *Scenario formulation and stakeholder dialogue* involves the construction of draft or "prototype" scenarios and their revision on the basis of stakeholder feedback, ideally through face-to-face dialogue, usually in small, specialist groups. Stakeholders can comment on the plausibility of the scenarios, their representation of uncertainties in projections, and their utility for potential users (e.g. Lorenzoni *et al*. 2000). Feedback from a range of stakeholders on a set of interim FINSKEN scenarios was obtained at a semi-

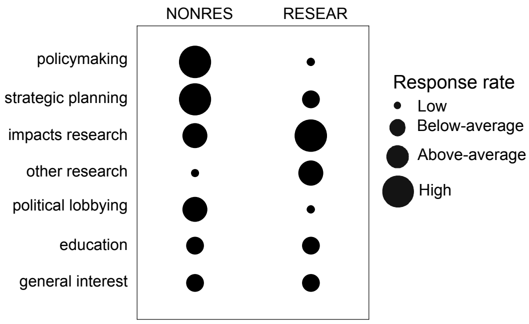

Fig. 4. A comparison between non-researchers (NONRES) and researchers (RESEAR) of the reasons for wishing to obtain FINSKEN scenarios (Bärlund and Carter 2002).

nar held in May 2001 (Carter 2001). In addition, formal, face-to-face dialogue sessions were conducted to support the development of long-term socio-economic and technological scenarios, with which there is little prior experience in Finland (Kaivo-oja *et al*. 2004).

3. *Scenario refinement and selection* involves the presentation of a set of refined scenarios to selected stakeholders representing key interest groups, and the selection of a few "core" scenarios, possibly within a workshop setting. Examples of this type of dialogue, involving global model developers and policy makers, include the Delft process (van Daalen *et al*. 1998) and the COOL dialogues (Tuinstra *et al*. 2002). The final FINSKEN scenarios were presented and debated at a final seminar held in November 2002 and attended by a cross-section of Finnish interest groups as well as five international experts (Carter 2002). Scenarios were also made available on the FINSKEN web site. However, formal participation of stakeholders in the process of refinement and selection of FINSKEN scenarios was precluded due to time and resource constraints.

Results

The FINSKEN scenarios are reported in detail by individual groups. This section attempts to summarise the major findings of the project, and to characterise future global changes in Finland according to the four SRES storylines.

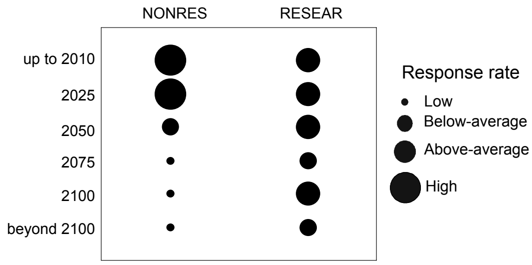

Fig. 5. Weighted positive response of the activity groups to the time horizons of projection (Bärlund and Carter 2002).

Questionnaire survey

There was a 30% response rate to the FINSKEN questionnaire survey, of which 93% indicated that they could or might make use of scenarios. Many of the responses followed a predictable course: for example, the focus on research needs among university and research institutes, in contrast to planning and policy needs in the government and private sectors (Fig. 4).

Priorities for scenarios differed between researchers and non-researchers. The research community required information over a wide spectrum of spatial and temporal resolutions and for time horizons ranging from 10 to 100 years. Conversely, non-researchers attached most importance to projections at low spatial and temporal resolution extending over time horizons up to 2025 (Fig. 5). Indeed, some respondents thought that scenarios extending to the year 2100 or beyond were "too much like fortune telling", though some acknowledged that longer time horizons are nevertheless needed to indicate the direction of possible change.

The FINSKEN scenarios: alternative views of Finland in the 21st century

Table 3 offers four alternative characterisations of socio-economic and environmental change in Finland during the 21st century, in the A1, A2, B1 and B2 worlds. In order to present the widest range of future emissions, the A1 scenario presented in Table 3 assumes a fossil intensive economy (A1FI). In terms of the environmental changes projected, the FINSKEN scenarios can be conveniently divided into two main groups. One group

Table 3. Summary of selected global change scenarios for Finland in four future worlds (A1FI, A2, B1 and B2) and for three future time periods (2020s, 2050s and 2080s).

Scenario type	Period	A1FI	A2	B1	B2
Population change[1]	2020s	+3.2	+3.4	+3.2	+2.2
(%, relative to 2000)	2050s	–0.2	+2.5	–0.2	–0.2
Present (2000): 5.2 million	2080s	–3.4	+11.5	–3.4	–0.9
Gross Domestic Product change[1]	2020s	+67	+49	+75	+49
(%, relative to 2000)	2050s	+186	+127	+155	+78
Present (2000): 170 bill. US1990$	2080s	+370	+253	+228	+139
Forest area change[2]	2020s	+1.1	+2.0	+0.2	+1.1
(%, relative to 2000)	2050s	+4.1	+8.3	–1.7	+3.4
Present (2000): 75.5% of land area	2080s	+8.9	+6.8	–0.1	+4.2
CO_2 concentration[3]	2020s	432	429	421	415
(ppm)	2050s	590	545	492	486
Present (2000): 367 ppm	2080s	829	718	534	567
Mean annual temperature change[4]	2020s	1.5–3.1	1.3–2.8	1.5–2.4	1.5–2.8
(°C, relative to 1961–1990)	2050s	3.8–5.2	2.9–4.0	1.8–3.5	2.1–3.7
	2080s	5.6–7.4	4.4–5.9	2.4–4.4	3.0–5.0
Annual precipitation change[4]	2020s	4–14	2 –13	3–14	3–16
(%, relative to 1961–1990)	2050s	9–28	7–21	4–17	1–20
	2080s	14–37	8–29	8–23	6–28
Sea level change — Vaasa (63°N)[5]	2020	–13	–13	–14	–14
(cm, relative to 2000)	2050	–29	–30	–32	–32
	2090	–38	–45	–54	–52
Sea level change — Hamina (61°N)[5]	2020	–2	–2	–3	–3
(cm, relative to 2000)	2050	+0	–1	–3	–3
	2090	+14	+7	–2	+0
Ozone exposure — Oulanka (66°N)[6]	2010	4700	4550	4490	4310
(AOT40f — ppb h)	2050	14850	9480	5240	7130
Present (1996–2001): 4180 ppb h	2090	27030	16330	3350	9150
Ozone exposure — Utö (60°N)[6]	2010	10290	10010	9890	9560
(AOT40f — ppb h)	2050	26400	18480	11290	14630
Present (1996–2001): 8040 ppb h	2090	41760	28420	7660	17960
S deposition — Rovaniemi (66°N)[7]	2020s	0.21	0.16	0.17	0.08
($g\ m^{-2}\ yr^{-1}$)	2050s	0.17	0.22	0.13	0.09
Present (1998): 0.30 $g\ m^{-2}\ yr^{-1}$	2080s	0.21	0.13	0.10	0.09
S deposition — Helsinki (60°N)[7]	2020s	0.59	0.46	0.47	0.20
($g\ m^{-2}\ yr^{-1}$)	2050s	0.49	0.64	0.35	0.22
Present (1998): 0.75 $g\ m^{-2}\ yr^{-1}$	2080s	0.61	0.35	0.22	0.24
N deposition — Rovaniemi (66°N)[7]	2020s	0.18	0.16	0.12	0.16
($g\ m^{-2}\ yr^{-1}$)	2050s	0.25	0.20	0.10	0.19
Present (1998): 0.17 $g\ m^{-2}\ yr^{-1}$	2080s	0.31	0.24	0.08	0.17
N deposition — Helsinki (60°N)[7]	2020s	0.34	0.31	0.23	0.30
($g\ m^{-2}\ yr^{-1}$)	2050s	0.48	0.39	0.20	0.37
Present (1998): 0.37 $g\ m^{-2}\ yr^{-1}$	2080s	0.60	0.46	0.15	0.32

[1] Gaffin *et al.* (2004), variants of these scenarios are described in Kaivo-oja *et al.* (2004); [2] Kankaanpää and Carter (2004); [3] Linearly interpolated from 10-yearly results of the Bern-CC model reference case — large uncertainties bound these central estimates (Prentice *et al.* 2001, Jylhä *et al.* 2004); [4] Jylhä *et al.* (2004); [5] Based on the data used to construct figure 7 in Johansson *et al.* (2004); [6] A1FI is represented by A1C; estimates are rounded to the nearest 10 ppb × h (Laurila *et al.* 2004); [7] A1FI is represented by A1C; interpolated from grid box results of the DAIQUIRI model (Syri *et al.* 2004).

(A1FI and A2) reflects a consumer-driven world that emphasises personal freedoms and economic growth, and the second group (B1 and B2) reflects a community-orientated world that stresses environmental concerns (vertical axis in Fig. 2).

The consumer-driven, A-world posits strong economic growth in Finland, shared by a population that may increase or decrease by 2100, depending on the scenario. However, in the absence of a global shift towards non-fossil energy sources, this will come at the expense of large environmental changes, including a doubling of present-day CO_2 concentration before the end of the century, increasing ozone pollution and nitrogen deposition, slightly increased levels of sulphur deposition, and rapid mean annual warming of more than 0.5 °C per decade with increasing annual precipitation of around 2% per decade. Currently falling sea levels in southern Finland could stabilise or begin to rise.

The community-orientated, B-world shows lower economic growth than scenarios for the A-world, with moderate increases in population followed by a general decline. Rising CO_2 concentration may begin to level off towards the end of the century as it approaches a doubling of pre-industrial levels. Ozone concentration and nitrogen deposition may increase somewhat by mid-century, but by 2100 deposition levels of both sulphur and nitrogen are unlikely to exceed present levels and will probably be much lower. Mean annual temperature and precipitation are estimated to increase at between half and two-thirds the rate under the A-world scenarios. Sea levels in southern Finland either stabilise towards the end of the century or continue to fall.

It should be noted that the adoption of advanced energy technologies to reduce fossil fuel emissions, as indicated by the A1T scenario (cf. Table 1), would produce similar environmental effects as under the B-world scenarios, while maintaining the economic and demographic profiles of an A-world (not shown in Table 2). For the A1T scenario to be effective for climate and sea level, the measures would need to be global. Alternatively, regional air pollution controls can be effective in reducing nitrogen and sulphur deposition over Finland, while ozone concentrations would be influenced both by regional and by global controls.

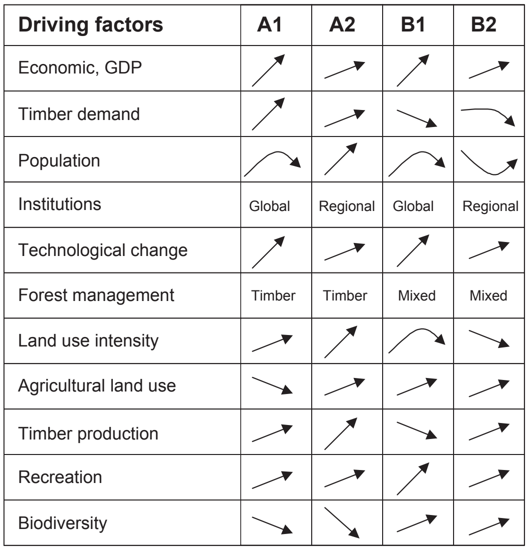

Fig. 6. Relative direction of the driving factors determining forest area in Finland, 2001–2100, in the four SRES worlds (Kankaanpää and Carter 2004). For instance, a tilted straight arrow denotes steady growth or decline throughout the century; a curved arrow indicates a change in rate of growth or decline.

Another way of portraying likely future trends under the SRES storylines is presented in Fig. 6, which shows different driving factors determining forest area in Finland. A qualitative representation of this kind can provide useful guidance for the subsequent preparation of a more quantitative assessment. For instance, under this interpretation of the A1 storyline, strong economic growth during the century in Finland and worldwide leads to increased global timber demand, which stimulates more intensive timber production in Finland, with expansion of forest area at the expense of agriculture and a reduction in biodiversity (Fig. 6).

Discussion

New features of the FINSKEN scenarios

Some novel features of the FINSKEN scenarios compared to scenarios prepared previously in Finland include:

— Consistency between different environmental and socio-economic scenarios has been

ensured by basing them all on the global IPCC SRES scenarios. Integration has been further enhanced by examining interactions between scenario types.
— All scenarios consider time horizons to 2050 or beyond, which is an extension of the conventional projection period for several scenario types.
— Long term socio-economic scenarios have been developed for Finland based on expert interpretation of the SRES storylines, quantitative modelling and stakeholder dialogue.
— New climate scenarios have been developed for Finland to supersede the SILMU scenarios, representing modelled responses across the range of SRES emissions. Moreover, results from high resolution model simulations have also been made available.
— A comprehensive set of sea level scenarios has been prepared for the Finnish coastline, accounting for global sea-level rise under the SRES scenarios, local land movements and possible changes in atmospheric circulation.
— Scenarios of tropospheric ozone and of the deposition of sulphur and nitrogen compounds have been prepared for an extended time horizon. They account not only for future changes in emissions (across a range of SRES and policy scenarios), but also for possible concurrent future changes in climate.
— FINSKEN scenarios can be accessed from a single site on the web: http://www.finessi.info/finsken.

Application of the FINSKEN scenarios

At the time of writing, the development of FINSKEN scenarios has only recently been completed. However, interim climate scenarios have already been applied in a number of climate change impact studies (e.g. Venäläinen *et al*. 2001a, 2001b, Haapala *et al*. 2001, Tammelin *et al*. 2002, Vajda *et al*. 2004), and a range of FINSKEN scenarios will be applied in the forthcoming FINESSI project on integrated assessment of global change impacts across a number of sectors.

Further work

The FINSKEN project has produced a limited set of integrated scenarios for Finland. Future research should focus on:

— Disseminating, maintaining and updating the current set of scenarios.
— Extending the set to include other socio-economic and environmental characteristics (e.g. non-forest land uses, social preferences, infrastructure, adaptation capacity).
— Refining the set to address alternative scenario construction methodologies and broader issues relating to uncertainty.
— Establishing the credibility and broad acceptance of global change scenarios through continuous interaction and dialogue with stakeholders throughout the process of scenario development.
— Exploring a wider range of policy-related scenarios to compare with the SRES reference scenarios (e.g. greenhouse gas stabilisation scenarios; other normative, target-based scenarios).
— Incorporating global change scenarios within an integrated assessment framework, to facilitate analysis of future global change impacts and potential response measures in Finland.

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