# Models and Systems

## Development of Energy System Models for Finland in Co-Operation with the IEA ETSAP Programme

*Suomen energia-päästömallien kehittäminen IEA:n ETSAP-yhteistyössä*

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### Abstract

The main objectives of the ETSAP project were threefold. Firstly, an important subtask of the project consisted of activities related to the Finnish national contribution and collaboration within the Energy Technology Systems Analysis Programme (ETSAP) of the International Energy Agency. The collaboration activities include the exchange of experiences, approaches and databases related to energy system modelling, as well as the development and dissemination of new modelling tools within the research community. Secondly, an important concrete goal was to take into use at VTT the new generation energy system modelling environment TIMES, which has been recently developed within ETSAP. Finally, another important objective was to apply the new modelling system to the analysis of future energy technology scenarios, by extensively utilizing the up-to-date technology characterization data produced by the Climtech Programme.

Participation in the ETSAP Programme has proved to be an effective means to take part in international collaboration on energy system studies. The regular semi-annual workshops provide an outstanding forum for the exchange of modelling experiences and results from national studies. As the ETSAP participants are among the leading international experts of bottom-up energy system modelling methodology, ETSAP provides a good reference group for coherent national modelling studies. The members of the project team had wide contacts with some of the core participants of the programme, and made notable contributions to the development of the TIMES modelling system. However, the implementation of the national TIMES model for Finland suffered from a number of initial deficiencies and shortcomings of the new modelling system, all of which were nevertheless overcome during the project. The completion of the full-scale national model was, however, delayed. Therefore, the Climtech scenario analyses were eventually made by using the EFOM model, which is a direct predecessor of TIMES. Detailed results from the scenario study are reported in the final report of the project.

### Tiivistelmä

Projektilla oli kolme tärkeää, mutta toisistaan melko erillistä päätavoitetta. Verrattain pieni, mutta silti tärkeä osa projektin resursseista oli varattu osallistumiselle IEA:n (International Energy Agency) ETSAP-ohjelman (Energy Technology Systems Analysis Programme) toimintaan. Yhteistyö ohjelmassa käsittää mm. osallistumisen työseminaareihin, mallinnuskokemusten ja tietokantojen vaihdon, sekä uusien mallinnustyökalujen kehitystyön ja levityksen. Toinen päätavoite oli ottaa käyttöön ETSAP-ohjelman piirissä viime vuosina kehitetty uuden sukupolven energiajärjestelmien mallinnusympäristö TIMES. Lopuksi tavoitteena oli soveltaa uutta mallijärjestelmää vaihtoehtoisten energiateknologian kehitystä koskevien ske-

naarioiden analysointiin käyttäen hyödyksi Climtech-ohjelman projektien tuottamaa tuoretta tietoa eri teknologioiden kehityksestä ja markkinapotentiaalista.

Osallistuminen ETSAP-ohjelmaan on osoittautunut hyödylliseksi keinoksi päästä mukaan laajaan kansainväliseen yhteistyöhön teknologialähtöisen energiajärjestelmätutkimuksen alalla. Kaksi kertaa vuodessa järjestettävät ETSAP-työseminaarit ovat erinomainen tilaisuus vaihtaa mallinnuskokemuksia ja saada tuoretta tietoa eri maissa tehdyistä analyyseistä. Koska ETSAP-ohjelmaan osallistuvat tutkimusorganisaatiot edustavat teknologialähtöisen energiajärjestelmätutkimuksen kansainvälistä huippuasiantuntemusta, ohjelma tarjoaa hyvän tukiverkoston yhtenäisin menetelmin ja lähtökohdin tehtäville kansallisille analyyseille. Projektiryhmällä oli runsaasti yhteyksiä keskeisiin ETSAP-ohjelman jäseniin, ja ryhmä kykeni antamaan näkyvän panoksen itse TIMES-mallijärjestelmän kehitystyöhön. Suomen TIMES-mallin rakentaminen tuotantokäyttöön soveltuvalle tasolle valitettavasti viivästyi mallijärjestelmässä vielä olleiden puutteiden ja ohjelmavikojen takia. Kaikki merkittävät ongelmat kyettiin kuitenkin projektin aikana ratkaisemaan, joten mallin viimeistelyssä ei tämän jälkeen ole enää odotettavissa vaikeuksia. Climtech-skenaarioiden mallinnus jouduttiin kuitenkin tämän vuoksi suorittamaan käyttäen TIMES- mallijärjestelmän erästä edeltäjää, EFOM-mallia. Skenaarioanalyysien tuloksia raportoidaan yksityiskohtaisesti projektin loppuraportissa.

## 1 Introduction

The need to participate in international collaboration related to energy system modelling was fully recognized in Finland after the agreement on the Kyoto Protocol in 1997 and the subsequent burden sharing discussion in the European Union. The IEA ETSAP Programme appeared to represent one of the most successful collaboration forums in this area, which led to the decision of joining the programme in 1999. Another good reason for participation in the ETSAP Programme was the need for improved energy system models. At VTT, the national EFOM energy system model has been regularly used for various national energy policy and technology studies since the early 1990s (van der Voort et al. 1984, Lehtilä and Tuhkanen 1999, Kemppi et al. 2001). However, the EFOM modelling system is actually becoming quite aged, and it lacks the scalability, user-friendliness, and a number of very useful modelling capabilities that are present in the newest generations of energy system modelling environments.

Originally, the ETSAP collaboration was planned to be funded through a new energy systems research programme. Due to the withdrawal of that programme, the ETSAP project was organized under the Climtech programme. In order to have some concrete benefits to the overall goals of the programme, the project plan was augmented with the application of energy system modelling to technology scenarios constructed on the basis of the results from the Climtech programme. The main objectives of the ETSAP project within the programme can thus be summarized as follows:

- To promote the use harmonized energy system modelling methodologies by active participation in the IEA ETSAP Programme;
- To participate in the development of new modelling tools within ETSAP;
- To introduce ETSAP's new modelling environment TIMES in Finland;
- To apply the most current energy system modelling tools available (TIMES, if possible) to the analysis of technology scenarios for the Climtech programme.

## 2 The IEA ETSAP programme

The International Energy Agency (IEA) maintains a wide energy technology and R&D collaboration programme. The purpose of the programme is to facilitate co-operation among IEA Member and non-Member countries to develop new and improved energy technologies and introduce them into the market. Research activities are set up under Implementing Agreements, which provide the legal mechanism for establishing the commitments of the Contracting Parties and the management of activities.

The objective of the Implementing Agreement on Energy Technology Systems Analysis Programme

(ETSAP) is to support the development of constructive, economically and technologically informed, policy options. The support is provided by establishing, maintaining and expanding a consistent analytical capability for single and multi- country energy/economy/environment studies, serving both national analyses and work in international forums. Key features are individual national teams, and a common, comparable and combinable methodology that permits in-depth national and multinational evaluations. The objectives of the ETSAP Programme can be summarized as follows:

- to perform comprehensive, consistent and comparable system analysis of energy/ economy/environment ($E^3$) issues;
- to provide information to national and international bodies;
- to promote and support global coverage of consistent analyses;
- to develop methodologies and tools for energy system analysis.

The core activities within ETSAP concern the application and ongoing development of a family of energy system models, named MARKAL (for MARKet ALlocation) (Fishbone et al. 1983, Goldstein and Greening 2001). These type of models allow policy analysts and decision-makers to identify and explore feasible energy technology scenarios that meet a range of constraints at the minimum overall cost over extended periods of time. The models can deal with various constraints and uncertainties, whether they concern eventual environmental requirements, the availability or acceptability of certain technologies, the availability and price of resources, or the future demand for energy services. Recently, a new generation modelling system, TIMES, has emerged within the ETSAP programme (ETSAP 2000).

With respect to future changes in the patterns of energy production, consumption, and the associated environmental impacts, technology is recognized to have a leading role. In order to capture the full potential of technology, the ETSAP methodologies and tools are accompanied by rich country-specific technology databases that are under constant revision and updating, and exchange between ETSAP participants to enhance harmonization and sharing of resources.

The ETSAP Programme has a long-standing tradition. It was founded in 1980 as the successor to a joint project launched by the IEA as early as 1976 with the aim to develop capabilities to analyze long-term energy futures and related R&D programmes. Currently, 14 active IEA member countries and the European Commission participate in the research programme: Australia, Belgium, Canada, Germany, Greece, Finland, Italy, Japan, the Netherlands, Norway, South Korea, Sweden, Switzerland, and the USA. Through collaborative projects, the ETSAP tools are used by over 75 teams in more than 35 countries for a variety of purposes, including preparation of national communications

**Table 1.** ETSAP annexes between 1980 and 2003.

| | Title or main subject | Years |
|---|---|---|
| I | Increase capabilities to analyze energy systems | 1980–1983 |
| II | Exchange data; promote and support common analysis | 1984–1986 |
| III | Energy and environment: Acid gases | 1987–1989 |
| IV | Energy and environment: Carbon dioxide | 1990–1992 |
| V | New directions in energy modelling | 1993–1995 |
| VI | Dealing with uncertainty together | 1996–1998 |
| VII | Contributing to the Kioto Protocol | 1999–2002 |
| VIII | Exploring energy technology perspectives | 2002– |

and related policies for the UN Framework Convention on Climate Change.

Despite its relatively low budgets the programme has achieved impressive results. As an international group of systems analysts, ETSAP was among the first to analyze energy-related environmental issues. ETSAP contributed to the acid deposition debate, and started to evaluate climate change mitigation costs already before the Rio conference. It provided environment policy analyses that were instrumental to the preparation of the Kyoto Protocol, and made a substantial contribution to the Third Assessment Report of the IPCC (WGIII). The current research focus includes the analysis of different international mitigation schemes by using regional and global models. On the whole, the programme provides a network of experienced analysts, each of which understand and recognize their national options and concerns. Consequently, ETSAP can be, and has proven to be, a very useful platform for international collaboration.

The programme has been organized into three-year subprogrammes or Annexes, which are listed in Table 1. Finland joined ETSAP in 1999, and the funding of the Finnish national collaboration was arranged through the Climtech programme.

## 3 The TIMES modelling system

The Integrated MARKAL-EFOM System (TIMES) is a bottom-up (i.e. technology-oriented) energy system modelling system based on the minimization of the overall discounted total system costs over a user-defined time horizon. Implicit assumptions in the model include perfect competition and perfect foresight. First versions of the modeling system are based on linear and mixed integer programming. Integer programming is needed for including endogenous technological change in the model. In a later phase other model versions using either non-linear programming of mixed complementarity formulation are planned to be supported. The model can be used for various analyses related to energy policies, energy technologies, and environmental implications.

Possible application areas of the model include the following:

- Least-cost strategies for achieving energy and emission policy targets;
- Economic evaluation of environmental and energy measures and actions;
- Examination of the collective potential of key technologies and resources;
- Evaluation of different R&D strategies;
- Evaluation of different energy policy options;

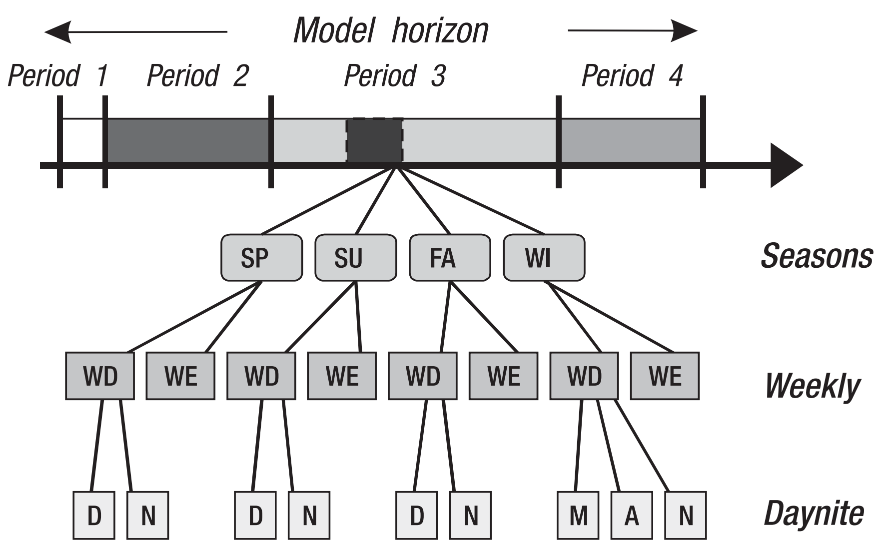


**Figure 1.** Example of a user-defined timeslice tree hierarchy in the TIMES model.

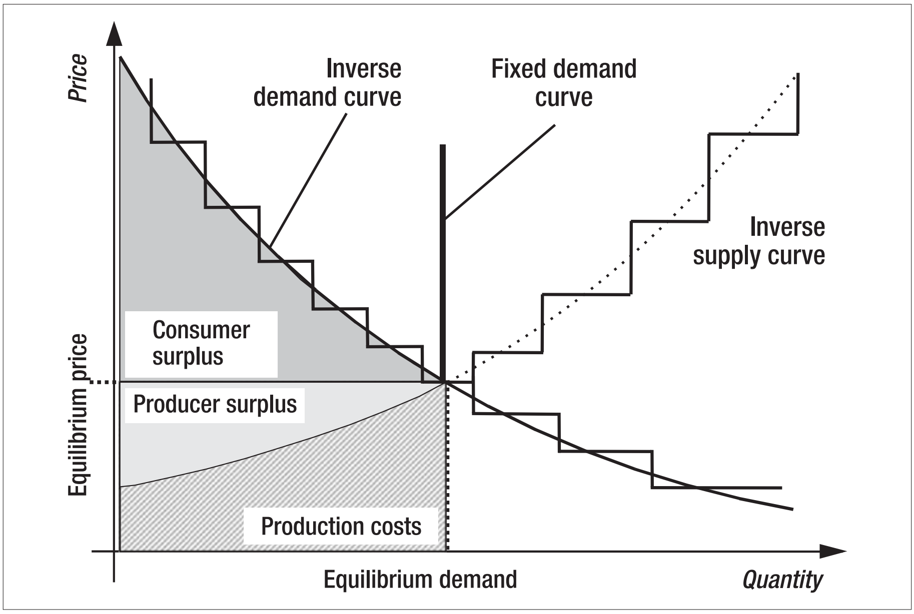


**Figure 2.** Principle of step-wise linear demand elasticities in the TIMES model.

- Assessment of alternative burden sharing systems (multi-country models).

In comparison with the EFOM model, which has for long been used at VTT, the TIMES system includes the following important enhancements:

- Flexible user-defined sub-annual time-slice hierarchy (see Figure 1);
- Genuine technology vintages and age-dependency of process characteristics;
- Various tools for describing inter-regional exchange of commodities;
- Genuine partial equilibrium modelling with elastic demands (see Figure 2);
- Endogenous technological learning (requires a MIP solver).

In addition, the TIMES system provides much better scalablility compared to EFOM, in terms of e.g. extended time horizons and regions, processes, commodities and emissions included in the model. Current plans for further enhancements include a macroeconomic linkage similar to Markal-Macro (Manne and Wene 1992), and multi-stage stochastic programming. In the future, a model version based on mixed complementarity formulation has also been considered to enable seamless linking with macroeconomic models.

## 4 Enhancements to theTIMES model generator

The core component of the TIMES modelling environment is the model generator. The generator transforms the structural and numerical data that describe the model into variables and equations that formulate a mathematical programming problem (see Figure 3). As an energy system model may consist of even hundreds of thousands of variables and equations, an efficient language is needed for the specification of the model.

In the TIMES system, the model specification language is based on the commercial General Algebraic Modelling System, GAMS. The TIMES model generator provides a good amount of predefined sets and parameters that are used for describing both model structure and numerical characteristics of technologies and commodities. The bulk of the data consists of time-series that describe the development of each characteristic parameter over time. Therefore, efficient tools for the specification

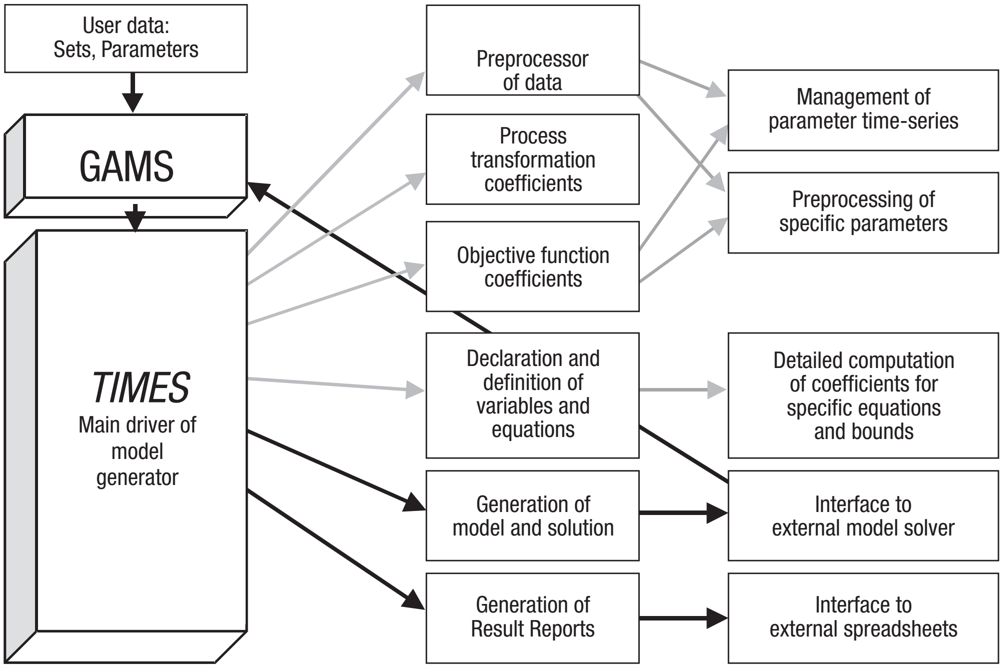


**Figure 3.** Functional relationships between components of the TIMES model generator.

and management of time-series data constitute an essential part of the model generator.

Within the Climtech project, the project team realized that the original tools included in TIMES for time-series management could be considerably enhanced by providing the user a set of additional options for the specification of time-series data. Therefore, a completely revised time-series management system was implemented for TIMES. The new facility greatly improves the independency of the years used for the specification of time-series data from the study years of individual model runs. As an additional bonus, the new system proved to be much more efficient in terms of computing speed.

On the basis of the experiences gained from using the EFOM model system, further improvements were introduced also in the set of predefined parameters and equation types in the TIMES model generator. These additions include e.g. the following:

- Generalized bounding constraint on process flows;
- Powerful new parameter and equation type for generalized relations between process flows;
- New parameter and equation type for the spcification of constraints on the market share of individual technologies in total commodity production;
- New parameter and equation type for the specification of by-products or ancilleries related to any flows tied to a process;
- New parameter for the spcification of bounds on the realative load within any individual timeslice;
- A set of 'metadata' parameters, which can be effectively used for automatic bulk generation of model data from fewer 'master' parameters, as well as a parameter for the easy specification of investment subsidies as percentages.

Moreover, the project team identified dozens of bugs in the TIMES code. Still further enhancements were also made in many parts of the code. For example, the calculation of the objective function was for major parts revised, the options for describing vintage-dependent availabilities were generalized, and the overall performance of the model generator was much improved. Proposed changes have been submitted to the ETSAP Software Coordinator for subsequent adoption into the standard version of TIMES.

## 5 The TIMES user shell

The amount of data needed for a full-size energy system model can very large, even in the case of a single-country model. In addition, model applications often require the running of a number of scenarios, or cases, based on different assumptions on the development of various technologies, energy prices, taxes, emission quotas etc. Consequently, the efficient management of all the data for different model cases, as well as model results, can be a very demanding task, and requires dedicated software tools.

Due to its high flexibility, the TIMES model is based on much more complex data structures than e.g. the EFOM model. Under the ETSAP Programme, a number of different solutions for a TIMES user shell have been prototyped, all of which are GUI applications running under Microsoft Windows:

- ANSWER-TIMES – Based on a widely used MARKAL user shell ANSWER developed by ABARE, Canberra, Australia;
- TIMESAP – Based on the Modular Energy System Analysis and Planning system MESAP developed at the IER, Stuttgart, Germany;
- VEDA – VErsatile Data Analyst developed by Haloa Inc., Montréal, Canada.

Unfortunately, none of these systems evolved to reliable production level shells during the Climtech project. Furthermore, the two shells that were made available to ETSAP partners, ASWER and VEDA, did not support all TIMES features, and were not extensible by design. In the end, it turned out necessary to develop a TIMES shell of own design at VTT. A fully working version of the VTT user shell was completed in May 2002. Relationships between major data objects of the shell are shown in Figure 4.

## 6 Model development

During the Climtech project, first modelling experiences with the TIMES model were obtained through a thesis project focusing on the construction of a pilot TIMES model for the electricity and heat generation systems of the Nordic countries. The thesis project was carried out by one of the team members at the University of Stuttgart, Institute of Energy Economics and Rational Use of Energy (IER), one of the most active participating organizations of ETSAP. While the pilot project itself was quite successful, it suffered from the fact that the TIMES system was still in its beta testing phase, and had to be operated without a user shell. The insights gained from this modelling exercise, and the results from the scenarios run with the Nordic model, have been reported in a Master's Thesis (Mäkelä 2001).

The problems related to the lack of a satisfactory TIMES user shell were evident practically throughout the Climtech project. While the various ongo-

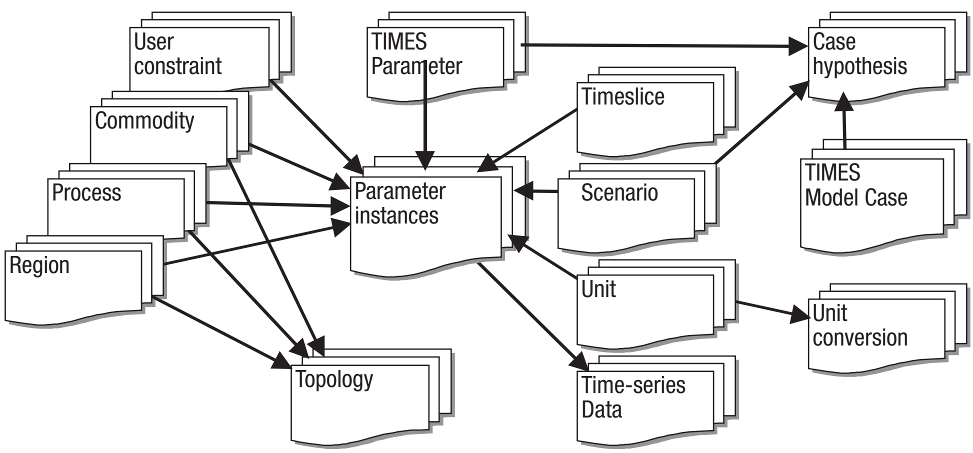


**Figure 4.** Main relationships between TIMES data objects in the VTT user shell.

ing shell development activities seemed to be very promising, the project team could not seriously start designing the tools necessary for data management without prior knowledge of the interfaces to the shell that would eventually be used. Therefore, for a large part the modelling work in the project was focused on the improvement of the current technology databases utilized for the EFOM model, so that the same database would be as up-to-date as possible, and readily disposable for the TIMES model. In this way the updated databases could be immediately utilized for long-term scenario analyses (Lehtilä 2001). This work could be fully used for the benefit of the Climtech scenarios irrespective of the model used. The database development work involved e.g. the following tasks:

- Further update of the earlier Climtech data for combustable fuel power and heat generation technologies (Savolainen et al. 2001), including REF plants;
- Extension and update of the database for wind and solar energy technologies;
- Update and collection of new data on space heating systems;
- Update of the data for the submodels of agriculture and waste management;
- Gathering of new data on energy conservation measures from Motiva databases and from the results produced by the Climtech programme;
- Collection of techno-economic data on $CO_2$ capture and disposal.

Even without an appropriate TIMES user shell, the project team managed to build a full-scale and functional power and heat generation model for Finland. In addition, prototype designs for the remaining sectors (e.g. industrial processes, households, space heating and transport) were completed. Other significant modelling work included the modelling of technical measures for reducing the F-gases and the introduction of the new dynamic emission model for the landfilling of waste. All of these tasks were directly serving both the Climtech scenarios and the forthcoming full-scale TIMES model.

## 7 Climtech scenarios studied

The coordinating group of the Climtech Programme specified the scenarios to be modeled and studied. The total study horizon was set to cover the years 2000–2040, of which the focus was set on the years years 2010, 2020 and 2030. Two possible future development paths were characterized for the scenarios:

- *'Conventional' development:* International measures for climate change mitigation evolve slowly. There is no major push for the development and commercialisation of cleaner technologies. As a result, the penetration of new energy technologies depends highly on economic policy instruments.
- *'Optimistic' development:* Accelerated climate change mitigation measures lead to rapid development and employment of cleaner technologies, both internationally and within Finland. Increased funding for both R&D and promotion of technologies reducing emissions has to be thereby assumed.

Emission reduction targets were assumed both for the Kyoto period in 2008–2012 and for the year 2030. The abatement levels studied for the year 2030 were 0%, –10%, –20% and –30% from the 1990 level. Scenarios were calculated considering all the six greenhouse gases included in the Kyoto protocol. The energy system model EFOM was used to find the least-cost allocations of greenhouse gas emission reductions in the alternative technology scenarios. Furthermore, the effects of carbon dioxide emission trading was considered in a few scenario variants. The model was also used for calculating other air pollutant emissions ($SO_x$, $NO_x$ and particulates) under the cost-effective greenhouse gas reduction solutions. The results from the scenario studies are reported in the final report of the project as well as in the summary report of the Climtech Programme.

## 8 Discussion and conclusions

The ETSAP Programme has proven to be a very important and productive forum for international collaboration in the field of energy system analysis. Members of the project team participated in all but one regular ETSAP workshop during 1999–2002. The new generation TIMES modelling system developed under the ETSAP Programme combines the strengths of two most widely used energy system models, MARKAL and EFOM. Perhaps the most important methodological advantages of the TIMES system compared to EFOM are the flexibility regarding both the representation of time segments and technology characteristics, and the capability of including demand elasticities, thereby reaching a genuine partial equilibrium model. By using the new TIMES system, the project team made various modelling experiments related to specific features of the Finnish energy system. In addition, a fully functional base model was implemented for the electricity and heat generation system. However, several serious obstacles for the development of a full national TIMES model emerged during the project:

- The former modelling environment used at VTT is the EFOM system, while the basic design of the TIMES system is largely inherited directly from the MARKAL model. The differences in the approaches rendered the task of converting an EFOM model into TIMES both difficult and prone to errors.
- The TIMES model generator was still under a validation stage. During the project, the Finnish ETSAP team disclosed a number of coding errors that had not been discovered by the primary software coordinators of ETSAP. VTT's new Quality System would not allow any deviations from high quality principles.
- Within the ETSAP Programme, many promising approaches for a TIMES user shell have been prototyped over the past years. However, as yet none of the systems has evolved to the level of flexibility and reliability needed for serious modelling work. Consequently, the Finnish team was finally forced to the development of a TIMES user shell and data management system from scratch.

As a consequence of these setbacks, the team could not reach the objectives originally set for real productive modelling work with the TIMES system. On the other hand, due to the difficulties faced with TIMES, considerable efforts had to be invested in the gaining of in-depth understanding of the TIMES model generator, as well as in the design and implementation of a fully functional user shell. Considering that the team had hardly any prior experience of building either GAMS or Microsoft Access applications, the results concerning the build-up of essential infrastructure for the TIMES modelling environment can be regarded quite satisfactory.

The completion of the full national TIMES model would still need a successive continuation project. As a consequence, the Climtech technology scenarios had to be eventually analyzed by using the EFOM model, which was nevertheless thoroughly updated with all the new technology data produced in the programme. For apparently similar reasons, the IEA Energy Technology Perspectives undertaking initiated in 2001 fell eventually back on using MARKAL, while it was originally planning to use the TIMES model.

Due to the ETSAP Programme having a major stake in the completion of the large ETP project, further development of the TIMES modelling system was practically frozen during 2002, but will definitely be resurrected in the near future. At all events, all the prerequisities for the successful final construction of the full-scale national TIMES model for Finland are now fulfilled. The completion of the model and subsequent model applications will greatly benefit from the ground work done related to quality assurance and model infrastructure, and from all the insights gained during the Climtech project.

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# Greenhouse Gas Balances of Biomass and Bioenergy Systems – Participation in an International Collaboration

*Osallistuminen IEA:n hankkeeseen "Greenhouse Gas Balances of Biomass and Bioenergy Systems" (IEA Bioenergy Task 38)*

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## Abstract

IEA Bioenergy is an organisation set up in 1978 to improve international co-operation and information exchange between national bioenergy research, development and demonstration (RD&D) programs. The work of IEA Bioenergy is carried out through a series of Tasks, each having a defined work programme. Currently there are 13 Tasks, one of them being *Greenhouse Gas Balances of Biomass and Bioenergy Systems* (2001–2003), Task 38. 12 countries including Finland are participating in this Task. The goal of Task 38 is to investigate all processes involved in the use of bioenergy systems on a full fuel-cycle basis with the aim of establishing overall GHG balances. Its main objectives are to 1) develop, compare and make available integrated computer models and other tools for assessing GHG balances of bioenergy and carbon sequestration systems and perform such assessments; 2) make comparisons of bioenergy systems with e.g. fossil energy systems, as well as comparisons of wood products with other materials such as steel and concrete; 3) analyse the country-level and regional potential of bioenergy, forestation, and other biomass-based mitigation strategies; 4) aid decision makers in selecting mitigation strategies that optimise GHG benefits; 5) assist in the implementation of forestry, land-use and bioenergy options through methodological work and development of standards for carbon accounting and contribute to the work of IPCC/OECD/IEA.

## Tiivistelmä

IEA Bioenergy on vuonna 1978 perustettu organisaatio, jonka tavoitteena on tehostaa kansainvälistä yhteistyötä ja tiedonsiirtoa kansallisten bioenergiatutkimus- ja tuotekehitysohjelmien välillä. IEA Bioenergyn työ jakautuu erillisiin tehtäväalueisiin (Tasks), joilla on kullakin omat erikseen määritellyt tehtävänsä. Tällä hetkellä on käynnissä 13 Taskia, joista yksi on *Biomassa- ja bioenergiajärjestelmien kasvihuonekaasutaseet* (2001–2003), Task 38. Kyseisessä Taskissa on mukana 12 osanottajamaata, näiden joukossa Suomi. Task 38:n päämääränä on tutkia kaikkia bioenergiajärjestelmien käyttöön liittyviä prosesseja ja tarkastella koko polttoainekierron kasvihuonekaasutaseita. Sen päätavoitteita ovat: 1) kehittää, vertailla ja levittää tietokonemalleja ja muita apuvälineitä, joita voidaan käyttää bioenergiajärjestelmien ja niihin liittyvien hiilinielujen kasvihuonevaikutusten arvioinnissa sekä analysoida tällaisia järjestelmiä, 2) verrata bioenergiajärjestelmiä fossiilisia polttoaineita käyttäviin ja puuperäisiä tuotteita kilpaileviin materiaaleihin kuten teräkseen ja betoniin, 3) analysoida bioenergia-, metsitys- ja muiden biomassan käyttöön perustuvien ilmastostrategioiden potentiaaleja valtakunnallisella ja alueellisella tasolla, 4) auttaa päätöksentekijöitä biomassaan perustuvien optimaalisten ilmastostrategioiden valinnassa sekä 5) antaa metodologista tukea metsitykseen, maan käyttöön ja bioenergiaan perustuvien vaihtoehtojen toteutukseen sekä hiilitaseen laskennan standardien muotoutumiseen vaikuttamalla mm. IPCC:n, OECD:n ja IEA:n verkostoissa.

# 1 Introduction

IEA Bioenergy is an international collaborative agreement, set up in 1978 by the International Energy Agency (IEA) to improve international co-operation and information exchange between national bioenergy research, development and demonstration (RD&D) programs. IEA Bioenergy aims to realise the use of environmentally sound and cost-competitive bioenergy on a sustainable basis, thereby providing a substantial contribution to meeting future energy demands.

IEA was founded in 1974 as an autonomous body within the OECD to implement an international energy programme in response to the oil shocks. Membership consists of 25 of the 29 OECD member countries. Activities are directed towards the IEA member countries' collective energy policy objectives of energy security, economic and social development, and environmental protection. One important activity undertaken in pursuit of these goals is a programme to facilitate co-operation to develop new and improved energy technologies.

IEA Bioenergy provides an umbrella organisation and structure for a collective effort where national experts from research, government and industry work together with experts from other member countries. Resources are provided in two main ways: Cost Sharing – participants contribute to a common fund for conducting research projects and information exchange. Task Sharing – participants devote specified resources and personnel to conduct an agreed work programme.

The work of IEA Bioenergy is carried out through a series of Tasks, each having a defined work programme. IEA Bioenergy currently has 13 Tasks, all of which are supervised by the IEA Bioenergy Executive Committee. Each Task has a defined work program and is led by one of the participating countries (Operating Agent). A Task Leader, appointed by the Operating Agent, directs and manages the work programme. In each country, a National Team Leader is responsible for the co-ordination of the national participation in the task. Each participating country pays a contribution towards the organisational requirements, and provides in-kind contributions to enable the participation of national experts in a Task.

Interest in reducing emissions of greenhouse gases to the atmosphere has increased largely due to awareness of the risk of climate change, and due to the adoption of the Kyoto Protocol. Countries are preparing to implement programs that aim at limiting emissions of greenhouse gases. Bioenergy is a very attractive option to pursue this goal. In particular, the IEA Bioenergy position paper (IEA Bioenergy Task 25) on bioenergy and greenhouse gases states: "Biomass can play a dual role in greenhouse gas mitigation related to the objectives of the UFCCC, i.e. as an energy source to substitute for fossil fuels, and as a carbon reservoir ... Modern bioenergy options offer significant, cost-effective and perpetual opportunities toward meeting emission reduction targets ... Moreover, via the sustainable use of the accumulated carbon, bioenergy has the potential for resolving some of the critical issues surrounding long-term maintenance of biotic carbon stocks. Finally, wood products can act as substitutes for more energy-intensive products, can constitute carbon sinks, and can be used as biofuels at the end of their lifetime".

IEA Bioenergy Task 38 on *Greenhouse Gas Balances of Biomass and Bioenergy Systems* (2001–2003), which continues work of the previous Tasks XV and 25 (Greenhouse Gas Balances of Bioenergy Systems) brings together the work of national programs in 12 participating countries on GHG balances for a wide range of biomass systems, bioenergy technologies and terrestrial carbon sequestration. The countries being involved are: Australia, Austria, Canada, Croatia, Denmark, Finland, New Zealand, Norway, Sweden, the Netherlands, United Kingdom and United States. The Task is lead by Bernhard Schlamadinger from Joanneum Research, Austria. The Finnish National Team Leaders are Ilkka Savolainen and Kim Pingoud.

The Task considers questions of carbon accounting in the land use, land-use change and forestry (LULUCF) sector under the United Nations Framework Convention of Climate Change (UNFCCC) and contributes to the work of the Intergovernmental Panel on Climate Change (IPCC). While Task

25 concentrated on scientific-technical and on methodological issues, there was an increasing demand for information that aids decision-makers in implementing programs to limit emissions or enhance removals of greenhouse gases. Therefore the scope of Task 38 is concentrating more on the application of methods, and on aiding the implementation of mitigation projects and programs. In addition, the work of Task 25 was increasingly looking at activities that enhance carbon stocks, or limit the loss of carbon stocks, in the terrestrial biosphere. Thus Task 38 attempts to reflect carbon sequestration issues by including the word "biomass" in its title.

## 2 Objectives of the Task

Task 38 builds on the achievements of Task 25, which concentrated on scientific-technical issues and method development. Task 38 focuses more on application of methodologies to GHG mitigation projects and programs. Objectives of the Task are listed in the following.

### 2.1 Scientific and methodological objectives

- To develop, compare and make available integrated computer models and other tools for assessing GHG balances of bioenergy and carbon sequestration systems on the project, activity, and regional levels, and address scaling issues between these levels.
- To assess the life cycle GHG balance of such systems, including leakage, additionality, and uncertainties. These analyses must integrate forest and agricultural sectors, bioenergy production and conversion, and carbon sequestration considerations.
- To make comparisons of bioenergy systems with e.g. fossil energy systems, as well as comparisons of wood products with other materials such as steel and concrete.
- To analyse the country-level and regional potential of bioenergy, forestation, and other biomass-based mitigation strategies, including implications for atmospheric $CO_2$ reduction.
- To identify and analyse the synergies between afforestation and other land-based activities for carbon sequestration and the enhanced use of bioenergy.
- In pursuit of the listed above, collaborate with other Tasks of IEA Bioenergy, for example, on conventional forestry, short-rotation forestry, techno-economic assessment, socio-economic aspects. The Task proposed here is cross-cutting in nature, and will rely heavily on exchange of information with these other Tasks

### 2.2 Objectives related to implementation

The following objectives relate to implementation of projects and of GHG inventories at various levels (including corporate and national), and national/international environmental agreements such as the Kyoto Protocol.

- To aid decision makers in selecting mitigation strategies that optimise GHG benefits, e.g. allocating biomass to energy vs. use as raw material; considering costs and benefits, as well as the practicalities of different mitigation strategies;
- To assist in the implementation of forestry, land-use and bioenergy options through methodological work and development of standards for carbon accounting in the energy and LULUCF sectors.
- To contribute to the work of IPCC/OECD/IEA related to GHG inventories of systems involving carbon sequestration, wood products, bioenergy, baselines in LULUCF.

## 3 Work and outcomes of the Task

### 3.1 Basic activities

The basic activities of the Task include:

1. *Task Workshops on a semi-annual to annual basis.*

   The organisation of workshops is a key element of the Task. The following were held during the first two years of operation:

   Canberra, Australia, 26–30 March 2001: Carbon accounting and emissions trading related to bioenergy, wood products and carbon sequestration.

Edinburgh, U.K., 12–13 November 2001: Successful strategies for biomass-based GHG emissions reduction and mitigation: translating research into policy and implementation.

Graz, Austria, 22–24 April 2002: The economics of substitution management to reduce net GHG emissions & Forest-based carbon mitigation projects: dealing with permanence, leakage, additionality, uncertainties, and socio-economic and environmental issues.

Amsterdam, Netherlands, 19 June 2002: Biomass Trade: Economic and Greenhouse Gas Considerations (biotrade).

2. *Special seminars with limited participation / target audience.*
3. *Expansion and development of the website.*
4. *Collection and updating of the Task bibliography.*
5. *Dealing with external inquiries related to the Task topic.*
6. *Design of a "Frequently asked questions" page on the website, dealing with greenhouse gases, bioenergy, land use, wood products and carbon sequestration, and aimed at decision makers and more generally a non-technical audience.*
7. *Collation and distribution of materials.*
8. *Special activities according to the short-term needs of participating countries*
9. *Regular distribution of information relevant to the Task topics.*
10. *Maintaining contact with the IEA Bioenergy Secretariat and the Operating Agent; preparing contributions for the IEA Bioenergy Annual Report, and regular Task progress reports for the Executive Committee Meetings.*

### 3.2 Standard methodology

The work within the Task is based on the application of the developed *standard methodology* (see IEA Bionergy Task 38 2002), which is a systematic framework for estimating the net GHG emissions for bioenergy systems and the energy systems they would displace. There are complicated trade-offs between carbon sinks in biomass and reduction of GHG emissions by bioenergy, where a dynamical analysis is needed.

Factors to be considered in such an analysis are as follows:

The carbon stocks in plants, plant debris and soils can change when biomass is grown and harvested. Such changes in carbon stock might extend over long periods of time, after which a new equilibrium is approached, thus necessitating time-dependent analyses. Afforestation or forest protection measures can be effective measures for mitigating the rise of $CO_2$ in the atmosphere, but may compete with biomass production for limited land resources. In such cases trade-offs between biomass harvest and carbon stocks in biomass must be considered. An example of synergy is that found in afforestation or reforestation with an integrated production system for wood and bioenergy, in which the stand is thinned to maximise value of wood production, and thinnings are utilised for bioenergy. Bioenergy provides an irreversible mitigation benefit when it displaces fossil fuels. Mitigation benefits of afforestation or forest protection will be lost if deforestation occurs.

The net benefit of using biomass energy depends on the carbon emission rates (amount of carbon emitted per unit of energy) of the displaced fossil fuels (e.g. oil or natural gas). For example, the net emission reduction of switching from coal to biomass will be greater than that of switching from natural gas to biomass, assuming all other factors such as conversion efficiencies remain unchanged. The efficiency of bioenergy systems (e.g. energy output per unit of feedstock energy or mass) may in some cases be lower than that of fossil energy systems. Recent technological developments have increased the efficiency of bioenergy systems considerably (e.g. Integrated Gasification Combined Cycle – IGCC). Production, transport and conversion of biomass fuels require auxiliary inputs of energy, which must be included in the assessment, as must the energy requirements for the supply of fossil fuels on which the reference energy system is based.

The use of biomass fuels does not always avoid the use of fossil fuels to the extent suggested by the amount of bioenergy actually used, a phenomenon commonly referred to as "leakage ". Bioenergy is often produced as a by-product. There are also cases where bioenergy is the main product and other by-products have to be considered. The emissions and offsets associated with both products and by-products must be estimated and allocated. Greenhouse gas emissions associated with both fossil and bioenergy fuel chains include not only $CO_2$, but other gases such as $CH_4$ and $N_2O$.

### 3.3 Frequently asked questions

"Answers to Ten Frequently Asked Questions about Bioenergy, Carbon Sinks and their Role in Global Climate Change" (F.A.Q. 2001) is a paper that aims to inform industry, researchers, policy makers and interested public about some key issues surrounding these topics. The FAQ explain:

1. The difference between $CO_2$ emissions from bioenergy and from fossil fuels;
2. How trees and forests act as a carbon sink;
3. The effect of harvesting on carbon sinks;
4. The area of land required to supply bioenergy to a power station;
5. The area of forest required to offset $CO_2$ emissions from a power station or from running a car;
6. The types of trees and crops that are best as carbon sinks or for bioenergy and wood production;
7. Integrated land management for carbon sinks, bioenergy and fibre production;
8. How the management of land as a carbon sink or for bioenergy production affects biodiversity and other environmental characteristics;
9. The potential to reduce greenhouse gas emissions by using bioenergy and through terrestrial carbon sequestration;
10. The current availability of technology to allow bioenergy to play a role in reducing atmospheric $CO_2$.

### 3.4 Case studies

Task 38 is applying the standard methodology to specific projects and helps increase experience that is useful in implementation of mitigation projects and programmes. Case studies are therefore conducted to assess and compare the GHG balances of different bioenergy and C sequestration projects in the participating countries. For example:

- In Australia GHG balances of two alternative bio-energy conversion systems (30 MW wood-fired power station, co-firing in a 500 MW black coal-fired power station) in North East New South Wales are compared. The biomass is produced from conventional plantation forestry.
- The New Zealand case study assesses the GHG balance of a sawmill in New Zealand, equipped with a combined heat and power (CHP) plant utilising sawmill residues of bark and sawdust. The current bioenergy system is compared to a reference system based on natural gas.
- In Canada the emission reduction of a small pyrolysis plant, which uses both thinnings from a juvenile spacing program and sawmill residues as feedstock, is examined. The plant produces bio-oil for subsequent use either in a pulp mill line kiln or for export.
- The Finnish and Swedish case studies look at the links between increased use of construction wood and the use of biomass-fired co-generation plants in comparison to fossil fuel use.
- The case study for the United Kingdom is targeted to compare small-scale bioenergy solutions for a rural community versus centralised systems of energy and heat generation, and bioenergy crops versus short-rotation forests versus long-rotation forests.
- In Croatia the GHG emissions reduction potential through biodiesel is assessed in the context of a potential Joint Implementation project.

The case studies are still in a preliminary stage and most of them will be carried out in an EU project starting early 2003. The project team is collected from the international research network formed under the Task 38.

### 3.5 Special activities of the Finnish team

The Task contributes to work in the context of National Greenhouse Gas Inventories, for example regarding approaches for estimating and accounting of $CO_2$ emissions from harvested wood products and biomass fuels or the development of IPCC Good Practice Guidance for national emissions inventories in the LULUCF sector. The Finnish team member Kim Pingoud is one of the Lead Authors in the above IPCC work and is responsible for the harvested wood products reporting.

The Finnish team also took part in writing answers to the 10 Frequently Asked Questions (F.A.Q. 2001). Presentations in the Task workshops often form draft versions of manuscripts, which later on have been published in international journals. Examples of such publications of the Finnish team are those of Pingoud and Lehtilä (2002) and Korhonen et al. (2002). The first one studies the secondary flows of fossil carbon in the lifecycle of wood-based products and the second one an accounting approach, which is aimed to describe the climatic impacts of short-term forestation projects.

Pingoud and Lehtilä (2002) show by the case study of the Finnish forest industries in 1995 that the main groups of wood-based products differ from each other substantially when considering the fossil C emissions of their manufacture in proportion to the wood-based C sequestered in the products themselves. These indices are useful measures when considering the possibilities of using various wood products as C sequestration options. Korhonen et al. (2002) analyse the so-called tonne-year approach, which has been strongly promoted in the debate on climate change mitigation. Their results show, however, that the approach applied to C accounting might even provide perverse incentives to forestation projects aimed at short- term C sequestration. In the long term this kind of project activities could even make matters worse and cause global warming, although the tonne- year measure would indicate a cooling impact.

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# Carbon sink of wood products

*Puutuotteiden hiilinielut*

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## Abstract

This paper focuses on the issue how the carbon in harvested wood products (HWP) can contribute to the mitigation of climate change and how this can be taken into account on country level carbon budget. Different approaches were tested using a model developed in this study. Practical application of this study is that the model can be used in the national greenhouse gas inventories. Furthermore, the effects of accounting methods on different countries were studied.

*Atmospheric-flow* approach favours exporting countries, by providing them an excess carbon sink, and the importing country gets an equal calculatory carbon emission. This causes barriers for trade, which could be harmful for wood use and forest industry. *Production approach* benefits producing countries and provides them incentives to export as much as possible. In *stock-change approach* only the stocks and stock changes of a country are taken into account. This approach seems to bring more benefits than the two other approaches and results in promoting of sustainable produced woody products.

## Lyhennelmä

Tässä tutkimuksessa tarkasteltiin puuperäisten tuotteiden mahdollisuutta sitoa ilmakehän hiilidioksidia ja täten ehkäistä fossiilisten polttoaineiden ja maankäytön muutosten aiheuttamaa ilmastonmuutosta. Erityisesti tarkastellaan erilaisten laskentaperiaatteiden vaikutusta maakohtaiseen raportointiin Kioton pöytäkirjan vaatimien velvoitteiden täyttämiseksi. Metsäteollisuustuotteilla paljon kauppaa käyvälle maalle, kuten Suomelle, on erittäin tärkeää, miten puutuotteiden viennin ja tuonnin sisältämän hiilen virta lasketaan tuotteita vievälle ja tuovalle maalle.

*Virtaperiaatetta* käytettäessä vievä maa hyötyy ja tuova maa saa saman kokoisen päästön. Tällöin puutuotteiden kaupalle voi muodostua vakavia esteitä, koska vievän maan täytyy yrittää kompensoida haitta jotenkin. *Tuotantoperiaatteessa*, jossa puuperäisten tuotteiden nielu lasketaan puun tuottaneelle maalle, puuperäisiä tuotteita vievä maa yrittää viedä mahdollisemman paljon, mikä voi aiheuttaa markkinahäiriöitä. *Varastonmuutosperiaatteessa* lasketaan vain kussakin maassa tapahtuvat varastonmuutokset. Tällöin maita rohkaistaan käyttämään kestävästi tuotettuja ja uusiutuviin raaka-aineisiin perustuvia puutuotteita. Yhden lisähankaluuden mahdolliseen Kioton pöytäkirjan mukaiseen laskentaan tuo se, että velvoitteet eivät koske kaikkia maailman maita.

# 1 Introduction

Forest ecosystems are a component of the terrestrial carbon (C) cycle and their management affects the carbon dioxide ($CO_2$) concentrations in the atmosphere. Wood-based products (in the following referred as *harvested wood products* = HWP) constitute an integral part of the C cycle of managed forest ecosystems. In *sustainable forestry* removals are in balance with forest growth in the long term, and the wood removed from forest by harvest can be viewed as a replacement for the natural mortality that would otherwise occur eventually.

HWP lifecycle can be utilised in mitigation of global warming both directly and indirectly: HWP form (1) a physical pool of C, (2) a substitute for more energy-intensive materials and, (3) raw material to generate bioenergy (IPCC 2001). In case (1) by growing the HWP pool itself, i.e. using it as C sink, atmospheric C can be sequestered. In case (2) and (3) HWP have lower greenhouse gas (GHG) emissions than the alternative material or fuel chain so that GHG emissions can be avoided indirectly by using HWP.

For the present the C balance of the physical pool of HWP is taken into account neither in the *reporting* included in the national GHG inventories under the United Nations Framework Convention on Climate Change (UNFCCC) nor in the C *accounting* due to the Kyoto Protocol. The main objective of this study was to analyse approaches and develop methods to estimate the carbon (C) balance in HWP, which eventually could be used for above reporting or accounting. Another objective was to consider HWP' role in material substitution, these results to be presented separately in a comprehensive project report.

# 2 Method for assessing C balance in HWP pools

At present the Intergovernmental Panel on Climate Change (IPCC) is developing *Good Practice Guidance* (GPG) for the Land-Use Change and Forestry (LUCF) sector to assist countries in performing their GHG inventories under the UNFCCC. The GPG is based on the IPCC *1996 Revised Guidelines* (IPCC 1997a, b, c), but it provides detailed methods to make inventories on the LUCF sector that are neither over- nor underestimated as far as can be judged, and uncertainties are reduced as far as practicable. In the *Revised Guidelines* the basic assumption is that there is no change in the size of the HWP stock (the so-called *IPCC default approach*). As the objective of the GPG is to provide best possible estimates, however, a more advanced approach is needed to describe the GHG balance in HWP. These HWP approaches are discussed in the following and calculation methods suitable for these approaches are presented.

Several studies have been carried out on the impacts of these measures on the amount of carbon sequestered in Harvested Wood Products (HWP). Approximate estimates on global C stock in HWP and their present growth rate can be found in the Second and Third Assessment Reports (SAR and TAR) of the IPCC (1996 and 2001). According to the SAR (IPCC 1996), the global stock of C in forest products would be of the order of 4.2 Pg C and the net sink 26 Tg C/yr. Other sources suggest a stock of 10–20Gt C (Sampson et al. 1993) and a global sink of 139 Tg C/yr (Winjum et al. 1998).

## 2.1 Accounting approaches

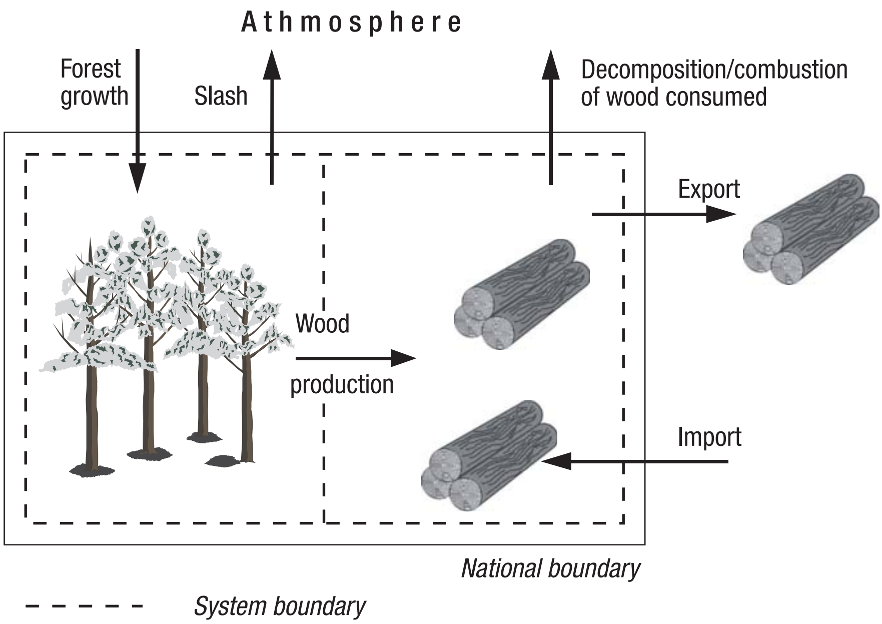
In the current IPCC default approach only emissions and removals related to forest stock change are considered. Emissions from harvested wood are attributed to the year of production and to the country of harvest, i.e. where the roundwood is produced. However, in the reality the carbon stock in HWP is changing and it can vary substantially between countries. The IPCC expert meeting in Dakar, Senegal (Brown et al. 1999), identified three alternative approaches for estimating the emissions and removals of $CO_2$ from forest harvesting and wood products. The approaches are summarised in Box 1 and illustrated in Figs. 1–3.

**Box 1.** The three alternative new approaches, identified in the Dakar meeting, for estimating net emissions from HWP (Brown et al. 1999).

***Stock-change approach*** – This estimates net changes in carbon stocks in the forest and wood- products pool. **Changes in carbon stock in forests** are accounted for in the country in which the wood is grown, referred to as the *producing* country. **Changes in the products pool** are accounted for in the country where the products are used, referred to as the *consuming* country. These stock changes are counted within national boundaries, where and when they occur.

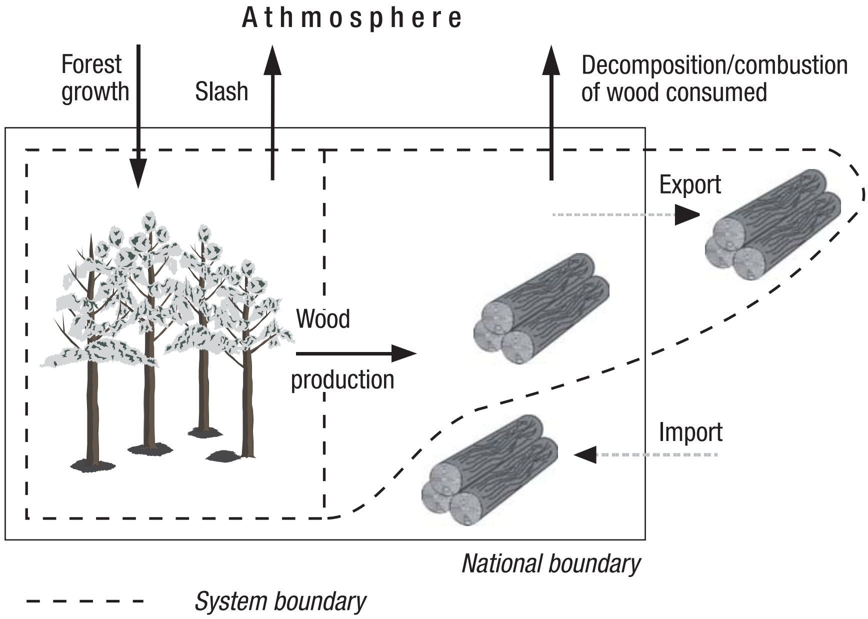
***Production approach*** – This also estimates the **net changes in carbon stocks in the forests and the wood-products pool**, but attributes both to the *producing* country. This approach inventories domestically produced stocks only and does not provide a complete inventory of national stocks. Stock changes are counted when, but not where they occur if wood products are traded.

***Atmospheric-flow approach*** – This accounts for net emissions or removals of carbon to/from the atmosphere within national boundaries, where and when emissions and removals occur. **Removals of carbon from the atmosphere due to forest growth** are accounted for in the *producing* country, while **emissions of carbon to the atmosphere from oxidation of harvested wood products** are accounted for in the *consuming* country.



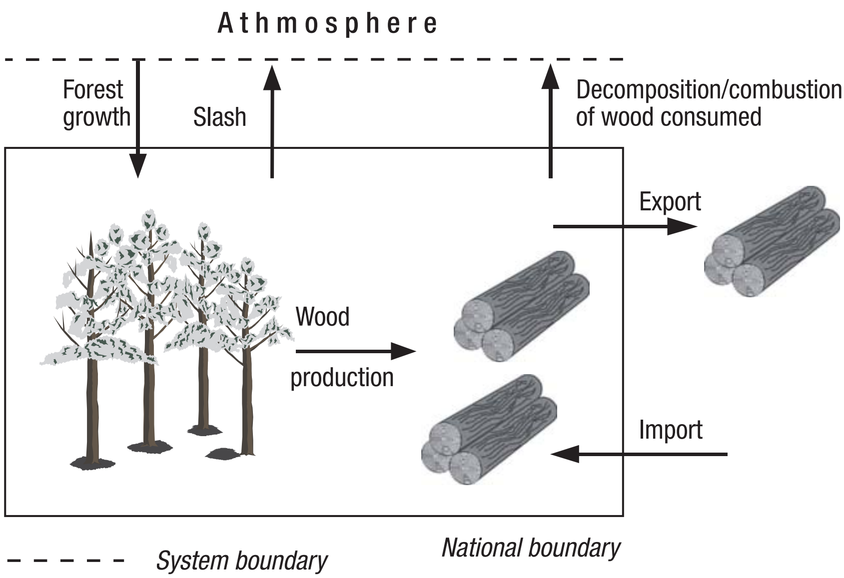

*Stock change = (stock change forest) + (stock change consumer products)*
*= (forest growth – slash-wood production)*
*+ (wood consumption – deconsumtion/combustion of wood consumed)*

**Figure 1.** Stock-change approach (Brown et al. 1999).




*Stock change = (stock change forest) + (stock change domestic-grown products)*
*= (forest growth – slash-wood production) + (wood production –*
*deconsumtion/combustion of wood grown in country)*

**Figure 2.** Production approach (Brown et al. 1999).




*Atmospheric flow = (forest growth – slash – deconsumtion/compustion of wood consumed)*

**Figure 3.** Atmospheric-flow approach (Brown et al. 1999). The atmospheric flow (from the atmosphere to the system) can also be expressed = (stock change forests) + (stock change consumed products) + net export.

## 2.2 The model and data

In this study an aggregated spreadsheet model for the C stock changes in HWP was developed. It is applicable to calculation of stocks and their changes in individual countries or country groups using different accounting approaches. As default data the model uses the global FAO Forestry database (FAOSTAT 2002), which includes the national production and international trade flows of the major groups of HWP, most compiled since 1961. The production prior to 1961 is estimated by exponential growth in the model. Using the consumption rates of HWP, converted to C flows, as input of the model and assuming an exponential decay of the HWP stocks in use, the C stocks and their changes are integrated in the model, starting from year 1900. The initial stocks in 1900 are approximated to be zero. In the model, two separate stocks of (semi-finished) HWP are considered, solid wood products (sawnwood and wood-based panels) and paper products (paper and paperboard), which differ from each other essentially in their use-lives. The spreadsheet also includes a model for changes of HWP stocks in landfills but their modelling includes lots of uncertainties and therefore results for landfills are not presented here. In the on-going work by the IPCC, where the Good Practice Guidance for the LUCF sector is developed, the above model is proposed to be the basic tool for estimating the C balances in HWP.

The model was numerically tested with data of several countries. The decay rate (or lifetime) parameters, however, were estimated only on the basis of Finnish data. The parameters were estimated by fitting the model output into sequential inventories of solid wood products in Finland. These inventories of the years 1980, 1990 and 1995 have earlier been presented by Pingoud et al. (2001), whereas the latest inventory of year 2000 was carried out for this study (Figure 4). The main model parameters are given in Table 1, in which the decay rate parameter of solid wood products represent simply a conservative estimate based on above inventories. The decay rates of Table 1 are equivalent to an average lifetime of solid wood products of 30 years and paper products 1 year, the corresponding half-lives

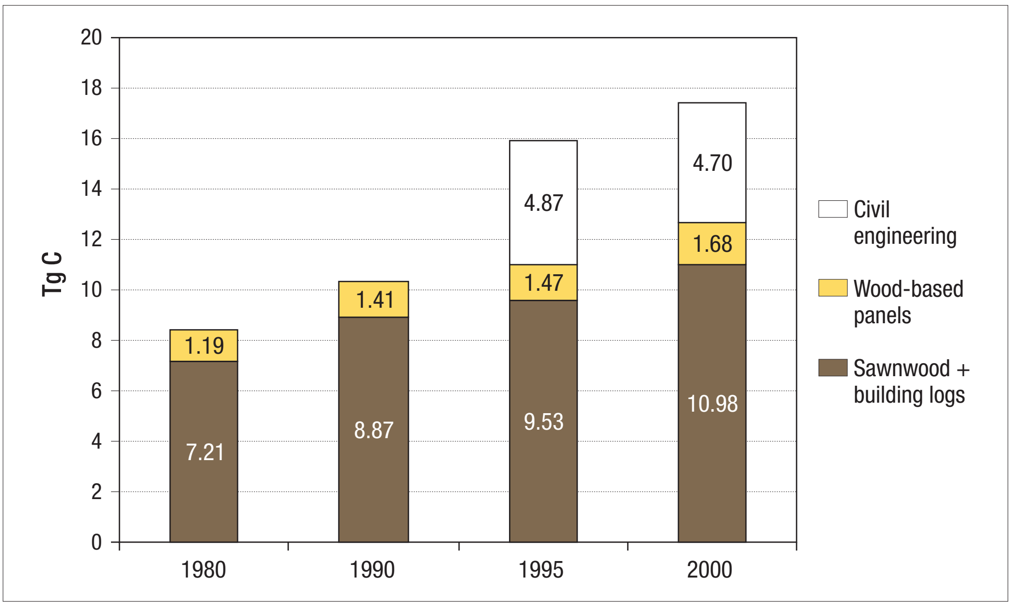



**Figure 4.** C stock inventory of solid wood products in Finland based on the statistics on construction and housing. Years 1980 to 1995 presented by Pingoud et al. (2001). Year 2000 by Perälä (personal communication, 2002). The figures of sawnwood and wood-based panels are based on building stock statistics, civil engineering on model calculations. The more uncertain figures on civil engineering were only estimated in years 1995 and 2000.

being 21 and 0.7 years. In addition, it was assumed that the yearly growth in production rates was 2% before 1961.

**Table 1.** Parameter values for the global C stock of HWP in use in the spreadsheet model (adt = air dry tonne).

| | Solid wood products | Paper products |
|---|---|---|
| Decay rate (1/yr) | 3.3% | 100% |
| Estimated growth of production prior to 1961 (1/yr) | 2% | 2% |
| Dry weight ($Mg/m^3$ and Mg/adt) | 0.45 | 0.90 |
| C content in dry matter | 50% | 50% |

## 2.3 Results

The outcomes of the three approaches for some selected countries were calculated with the above model, the results being illustrated in Table 2. The carbon balance of HWP (expressed here as Gg $CO_2$) are given and compared to 1) total GHG emissions (in Gg $CO_2$ equivalent) excluding Land-Use Change and Forestry (LUCF) in the base year 1990 and 2) emissions from LUCF, as reported in the national GHG inventories. The countries selected are industrialised countries committed to the Kyoto Protocol (Annex B). In case HWP were included in the C accounting due to the Protocol, which could happen in the second commitment period at the earliest, HWP would have an impact on the assigned amounts of above countries.

Considering first the *stock-change approach*, we see that HWP in use is a sink for *all* the selected countries in 2000, the highest sink in proportion to base year emissions estimated for Austria and Finland. However, the sink estimates by the model appear to vary more or less yearly depending on the HWP consumption. For instance in Finland, HWP formed a C source in year 1991. Some bias is caused by the fact that trade and consumption of final products are excluded from the numbers of Table 2. The FAO statistics being the basis of the model includes only roundwood and semi-finished HWP. Thus, for instance, furniture and pre-fabricated houses manufactured in a country but exported has been counted in the stock-change of the producer country. Denmark is an example of such a country. However, according to Table 2 stock change in HWP appears to be quite a significant factor in the countries' GHG balance, especially compared to the *reduction commitments* in Annex B of the Kyoto Protocol. As these are on average about 5% of the base year emissions, stock changes in HWP could in theory contribute to a remarkable portion in emission reductions. Note also that in some countries with small forest area the estimated changes in HWP stocks are much larger than stock changes in the LUCF sector.

*Production approach* appears to be less favourable than stock-change approach for most of the selected countries. One reason for this is the concentration of roundwood production in fewer countries than consumption of HWP, the wood producing and exporting countries taking all the advantage of the growing HWP stocks.

Maybe most interesting are the numbers for *atmospheric flow approach*. (Here the given numbers do not give the total *atmospheric flow* in Figure 7 but the sink additional to *stock change in forests*, i.e. = *(stock change consumed products) + net export.*) From the results we note some countries (Finland, Sweden and Canada) with very large additional sink due to HWP. In case of Finland the sink due to HWP would be **more than 30%** of the total base-year emissions! The numbers become understandable when bearing in mind that the sink consists of two terms of which the net export term dominates totally the C removal of the above exporter countries giving a huge credit to their national C balance.

**Table 2.** Total CO2 emissions excluding LUCF and emissions from LUCF for the base year 1990, reported in the national communications under the UNFCCC. Calculated *additional emissions* from HWP in 2000 using the three approaches and compared to reported base-year emissions according to the developed model. Note that negative numbers means carbon sinks. The input data of the model, the production and trade data since 1961, are from the FAO database (FAOSTAT 2002). Parameter values of the model are given in Table 1.

| **Greenhouse gas emissions** | Total without $CO_2$ from LUCF | $CO_2$ from LUCF | $CO_2$ from HWP, **Stock-change Approach** | | | $CO_2$ from HWP, **Atmospheric-flow Approach** | | | $CO_2$ from HWP, **Production Approach** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **$CO_2$ equivalent (Gg)** | Base year 1990 | Base year 1990 | 2000 | % of total base-yr | % of LUCF base-yr | 2000 | % of total base-yr | % of LUCF base-yr | 2000 | % of total base-yr | % of LUCF base-yr |
| Australia | 417575 | 76206 | -2061 | -0.5 % | -3 % | -443 | -0.1 % | -1 % | -2117 | -0.5 % | -3 % |
| Austria | 76939 | -9215 | -3088 | -4.0 % | 34 % | -3355 | -4.4 % | 36 % | -1835 | -2.4 % | 20 % |
| Belgium | 142396 | -1256 | -1443 | -1.0 % | 115 % | 1342 | 0.9 % | -107 % | -694 | -0.5 % | 55 % |
| Canada | 604717 | -59032 | -9207 | -1.5 % | 16 % | -91509 | -15.1 % | 155 % | -33848 | -5.6 % | 57 % |
| Denmark | 69953 | -916 | -1892 | -2.7 % | 207 % | 2286 | 3.3 % | -250 % | -106 | -0.2 % | 12 % |
| Finland | 77093 | -23798 | -2381 | -3.1 % | 10 % | -23582 | -30.6 % | 99 % | -4484 | -5.8 % | 19 % |
| France | 545665 | -52020 | -6707 | -1.2 % | 13 % | -2995 | -0.5 % | 6 % | -8077 | -1.5 % | 16 % |
| Germany | 1206637 | -33719 | -10844 | -0.9 % | 32 % | -6725 | -0.6 % | 20 % | -12566 | -1.0 % | 37 % |
| Greece | 105333 | 1391 | -591 | -0.6 % | -42 % | 1536 | 1.5 % | 110 % | -52 | 0.0 % | -4 % |
| Japan | 1175558 | -83824 | -1187 | -0.1 % | 1 % | 29843 | 2.5 % | -36 % | 5153 | 0.4 % | -6 % |
| Netherlands | 215798 | -1500 | -966 | -0.4 % | 64 % | 4792 | 2.2 % | -319 % | -458 | -0.2 % | 31 % |
| phaNorway | 46805 | -9590 | -720 | -1.5 % | 8 % | -1409 | -3.0 % | 15 % | -182 | -0.4 % | 2 % |
| Portugal | 64644 | -3994 | -1146 | -1.8 % | 29 % | -2690 | -4.2 % | 67 % | -660 | -1.0 % | 17 % |
| Spain | 305832 | -29252 | -5512 | -1.8 % | 19 % | 7848 | 2.6 % | -27 % | -1293 | -0.4 % | 4 % |
| Sweden | 69562 | -20292 | -1051 | -1.5 % | 5 % | -18397 | -26.4 % | 91 % | -2808 | -4.0 % | 14 % |
| UK | 741882 | 8791 | -3434 | -0.5 % | -39 % | 15068 | 2.0 % | 171 % | -3073 | -0.4 % | -35 % |
| USA | 6038192 | -1059900 | -72571 | -1.2 % | 7 % | -40302 | -0.7 % | 4 % | -46085 | -0.8 % | 4 % |

The importance of the trade in atmospheric flow approach is illustrated in Table 3. In atmospheric-flow approach the net exports of HWP (negative imports in Table 3) provide the leading exporter countries with a huge additional removal, whereas all the net importer countries would get an extra emission. Finland, Sweden and Canada could in principle take care of all their reduction commitments by exporting HWP, if atmospheric flow approach were chosen as the accounting framework. On the other hand, significant additional emissions would be allocated to Denmark, Spain, the Netherlands, Japan and UK.

**Table 3.** Net imports of HWP in 2000 converted to $CO_2$ flows and compared to base-yr emissions. Final products are excluded from these

| $CO_2$ (Gg/yr) | Net imports 2000 | % of base-yr emissions |
|---|---|---|
| Australia | 1617 | 0.4% |
| Austria | -267 | -0.3% |
| Belgium | 2785 | 2.0% |
| Canada | -82303 | -13.6% |
| Denmark | 4179 | 6.0% |
| Finland | -21201 | -27.5% |
| France | 3712 | 0.7% |
| Germany | 4118 | 0.3% |
| Greece | 2127 | 2.0% |
| Japan | 31029 | 2.6% |
| Netherlands | 5758 | 2.7% |
| Norway | -689 | -1.5% |
| Portugal | -1544 | -2.4% |
| Spain | 13361 | 4.4% |
| Sweden | -17346 | -24.9% |
| UK | 18501 | 2.5% |
| United States | 32269 | 0.5% |

## 2.4 Conclusions

All the three approaches are equivalent in describing the dynamical global C balance (emission/removal) of forests and HWP. This means that all the approaches assign the emissions/removals *when* they really occur, whereas the IPCC default approach assigns emissions/removals at the time of harvest. The fundamental difference between the atmospheric-flow and the other two approaches is the different perspective to the C balance. The atmospheric-flow approach considers within the national boundaries the C flows from the atmosphere to the forests (sink) and from decaying organic matter and HWP to the atmosphere (source). The other two approaches consider changes in C stocks of forests and HWP and interpret them as sink or source. Production approach also considers C stocks, which are outside the national boundaries. As a consequence of the different viewpoints the outcomes of the approaches differ in *where* the emissions/removals are assigned, *i.e.*, to which country they are allocated. Whichever of the approaches is chosen for national emission reporting the same approach must be applied in all countries and both to forests and HWP to avoid double-counting and no-counting situations.

In addition to be only *reported* for the UNFCCC, HWP could be included in the Kyoto *accounting* in the future. In this latter case the C accounting could create strong potential incentives for the use and international trade of HWP, as they may have direct economic consequences for countries being compelled to the commitments of the Protocol. This inclusion could be topical in the second commitment period at the earliest. However, the accounting rules negotiated in the future are not necessarily similar to anyone of the approaches. For example, some additional discount factors or caps could be applied to C accounting of HWP etc. The interesting point in accounting is, however, that if not all countries in the world are compelled to the commitments of the Kyoto Protocol, an asymmetric situation creating additional incentives to international trade of HWP between compelled and non-compelled countries.

As there are no decisions on the accounting rules and, for example, we do not know the market conditions of C, the quantitative assessment of incentives and disincentives are highly speculative at the moment. Factors like cost of reducing emissions, discount rates and international price of C will determine the true outcomes of the potentially strong incentives provided by HWP approaches in C *accounting*. Therefore, the incentives are discussed in the following only qualitatively, relative to each other rather than in absolute terms.

The outcomes and incentives of the approaches have been discussed extensively in the literature earlier. A good summary is presented e.g. in the Dakar meeting report (Brown et al. 1999). Some notable points were also presented in the Edmonton statement (Apps et al. 1997). The incentives of the three approaches compared to the IPCC default approach are shortly given as follows:

1. The stock-change approach gives a sink for building up of national forest and HWP stocks whereas the IPCC default approach neglects the changes in HWP stocks. In national reporting stock-change approach is neutral with respect to international trade in HWP. Whether HWP are produced within national boundaries or imported, growth in HWP stock is considered a C removal and its decrease an emission.
2. The basic feature of the atmospheric flow approach is separation of biological sinks and sources from each. Then in fact no incentives are provided to utilise the closed C cycle of HWP through the atmosphere (Atmosphere →Forest → HWP → Atmosphere) as a pump of renewable bioenergy, as the emission part of the above sustainable cycle is penalised (by treating biofuels like fossil fuels). In atmospheric-flow approach net import of HWP is reported as an emission and net export as a removal, in addition to the removal/emission due to stock increase/decrease. A country conducting forest harvest without replanting, reports no $CO_2$ emissions to the extent that harvested material is transferred to another country. Thus atmospheric-flow approach provides a disincentive for the use of imported HWP and imported wood-based fuels are treated similar to fossil fuels. Even if country A reports zero $CO_2$ emissions after burning self-produced biomass fuel, country A would be better off, if the biomass were sold to country B rather than using it himself. There are, of course, incentives to grow forests and HWP, but purchase and/or use of HWP is uniformly discouraged by the atmospheric-flow approach (Apps et al. 1997).
3. In production approach the wood-producing country gets an additional sink due to exported HWP. However, consistently stock decrease would be considered as a source for the producing country. Production approach provides incentives for a country to increase the stocks of those HWP grown in its own forests. However, those HWP are not necessarily inside its boundaries and thus not influenced by its own policies. The production approach may not provide an incentive to an importing country to better manage the use of imported wood since emissions are accounted for in the producing country. Another drawback of the production approach is that the importing country has little incentive to improve the management of waste and reduce the emissions (Brown et al. 1999).

In practice, the approaches may provide more complicated indirect incentives. Crediting of HWP stocks in stock-change approach can increase the use of long-lived HWP in case a market potential exists, and consequently also international trade of long-lived HWP could be boomed. In theory, as the importing country in production approach would get no credit for its increasing stocks, it does not have any incentives to increase the lifetime of HWP in the export markets (or even assist in reporting HWP stock changes). Also here it should be noted that there are severe practical difficulties to verify the stock changes of the exported HWP. The approximate estimation methods needed for production approach may to some extent change its incentives and impacts on international trade on HWP. Atmospheric-flow approach gives credits for exporting of HWP and debits for importing forming a kind of a zero-sum game. This could cause pressure on international market price of HWP in case HWP were included in Kyoto *accounting*. In addition, the (potential) ecological image of all HWP would be threatened, as their emissions if included in *accounting* would be calculated like fossil fuels.

A particular issue is how the different approaches handle trade of biofuels produced from wood. The atmospheric-flow approach does not provide an incentive to switch from fossil fuels to imported biofuels, because emissions from biofuels are accounted for in the consuming country, and the $CO_2$ emissions per unit energy output (MJ) are higher for biofuels than for most fossil fuels. But the exporting country would benefit by a decrease in national emissions. In fact, atmospheric-flow approach treats imported biofuels like fossil fuels are treated in the present accounting system. For the other approaches there is an incentive to switch from fossil fuels to imported biofuels, because the emissions from imported biofuels are accounted for in the producing country. For domestically grown biofuels all approaches provide incentives to switch from fossil fuels because harvest can be balanced by re-growth.

To illustrate the relative magnitude of the factors providing incentives in different approaches it is interesting to compare the estimated magnitude of global C stock change in HWP and the C fluxes of international HWP trade flows with each other. This gives an insight on the two factors affecting the reported C emission in atmospheric-flow approach. An approximate conservative estimate of the present global C stock change of HWP in use, given in Chapter 2, was a growth of 30–40 Tg C /yr excluding HWP in landfills. However, in 2000 the C flow of the whole international trade of HWP was more than 130 Tg C /yr, this number calculated by converting the global trade flows given in the FAO statistics (FAOSTAT 2002) into carbon. These numbers are illustrative and show that actually the global stock change in HWP appears to be much smaller than the zero-sum part of international imports and exports, which in atmospheric-flow approach would be reported as source for net importers and as sink for net exporters. Even if stock changes in HWP would be zero, these trade flows would create permanent emissions for net importers and removals for net exporters.

One issue is the development of HWP stocks in time. In general, they may form a C sink only as long as their consumption is increasing. However, their stock in future will saturate sooner or later or the stock will even decrease and form a C source This has to be borne in mind when assessing the long-term consequences of HWP accounting. For instance, in production approach a HWP exporter may be in future responsible for significant emissions taking place outside its own borders and without any possibilities to influence on this development.

## 3 Final remarks

The impact of HWP on GHG balance of the atmosphere can be considered from different perspectives. The first viewpoint is simply the balance of wood-based C associated with the lifecycle of HWP and timing of the C emissions into the atmosphere during their lifecycle, which was considered in the above study. HWP as a C pool are not yet included in the national GHG emission inventories, and thus this issue is lively discussed at the moment.

The viewpoint can be extended by further taking into account all the side-fluxes of *fossil* C emissions associated with the lifecycle of HWP, resulting mainly from fuel-use in production, transport and other stages of the cycle. A case study on these emissions in Finland was presented by Pingoud and Lehtilä (2002). The lifecycle fossil C emissions are, however, already included in the current reporting system (IPCC 1997a, b, c), and together with the wood-based ones considered above, represent *absolute* C emissions from the HWP lifecycle.

A more extended view is to consider the use of HWP as substitutes for other products. In spite of the above absolute GHG emissions due to HWP, they can be a favourable choice *compared to* alternative products. With wood-based fuels we can replace especially fossil fuels, and with HWP also more energy-intensive materials, which means that we can generate relative GHG emission reductions by using HWP (Hall et al. 1991, Marland and Schlamadinger 1995, 1997). The previous study by Pingoud and Perälä (2000) concerned the relative GHG balance, if the use of HWP were maximised in Finnish new construction. One part of the present Climtech-study not reported here is a micro-level case, in which the GHG impacts of building a wooden multi-storey house is compared with those of a similar one built in concrete.

The sink capacity of HWP is so limited that it cannot hinder $CO_2$ increase and the increasing stock can only mitigate $CO_2$ increase in the atmosphere for some time. While C sequestration in HWP can reach saturation, the C benefits of energy and materials substitution can be sustained.

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# Developing and Testing of Renewable Energy Certificate System (RECS)

*Uusiutuvan energian sertifiointijärjestelmän kehittäminen ja testaus (RECS)*

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## Abstract

The objective of this study was to develop and test procedures and a system for the trading of green certificates. RECS procedures for Finland were developed for the purpose of auditing production devices and for issuing and trading the certificates. A web-based certificate register was also developed and implemented.

## Lyhennelmä

Tämän tutkimuksen tavoitteena oli kehittää kaupankäyntijärjestelmä, jossa uusiutuvilla energiamuodoilla tuotetun sähkön ympäristöominaisuudella voi käydä kauppaa. Hankkeessa kehitettiin sertifikaattien myöntämistä ja ylläpitoa varten web-pohjainen rekisteri sekä otettiin käyttöön Suomessa eurooppalaisen RECS-hankkeen mukaiset menettelyt voimalaitosten rekisteröimiseksi, sertifikaattien myöntämiseksi sekä kaupankäynnin hoitamiseksi.

## 1 Introduction

RECS means the “Renewable Energy Certificate System”. It enables many types of support schemes, rather than being a support scheme itself, and it is not restricted by national boundaries. The RECS concept was presented for the first time 1998, and the idea for introducing a test phase to demonstrate the operational functionality of the RECS concept was proposed in 1999. Later on, it was decided that the test phase was to be implemented during January 2001 to December 2002.

The RECS concept is based on the voluntary trade of renewable energy certificates. The RECS system is now working in 7 countries in Europe having above 100 members, and the RECS idea has also been recognised world-wide. Finland has been involved in RECS from the beginning.

RECS provides a mechanism for representing a specific instance of electricity production of a megawatt hour of renewable electricity by a unique certificate which can be transferred from owner to owner before being used as proof of generation, or exchanged for financial support. The trade of RECS certificates is separated from the trade of physical electricity, as seen in figure 1.

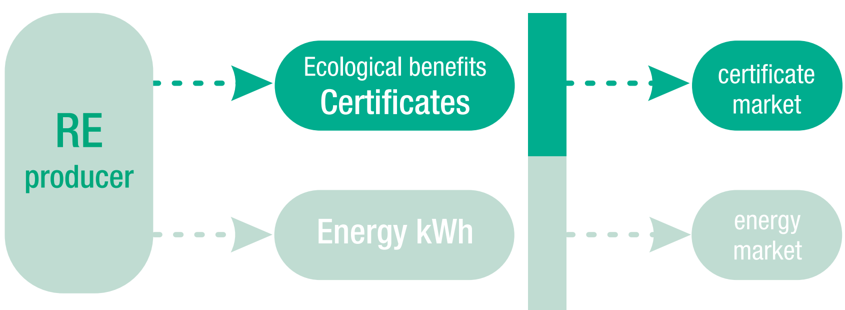


**Figure 1.** RECS principle.

To ensure that national systems are harmonised, built to the same standards and compatible with each other, RECS members have developed and adopted a set of rules: the Basic Commitment (BC).

RECS is administered within each geographical area by an Issuing Body (IB), which is unique to this area and independent of other members of RECS. Fingrid Oyj is the IB for Finland. All IBs are members of the international Association of Issuing Bodies (AIB), which guarantees the compatibility and adherence to the BC of the various national certificate systems. In addition, the commercial operations of each IB are subject to peer review by the AIB.

Each participating RECS country has a National Team representing the RECS members, IB, and other governmental or environmental organisations of that country. The National Team chooses the national representatives to different RECS forums and co-ordinates the RECS work on the national level.

Each RECS certificate is uniquely identifiable, transferable and therefore tradable, and contains standard information – including: a unique certificate number, issuer, generation plant identity, time of issue, type of technology, installed capacity, and an indication of whether public support has been received.

The life cycle of a RECS certificate is as follows:

1. **Issue**: A RECS certificate is issued for, and uniquely relates to, a specific instance of the production of a standard quantity – one megawatt hour – of renewable electricity.
2. **Transfer**: Each RECS certificate is registered as belonging to a single party at each point during its life, this being adjusted accordingly following each transfer of its ownership.
3. **Redemption**: RECS certificates are redeemed when they are “used”.

# 2 RECS process

RECS certificates are created, change owners and are eventually redeemed under a carefully developed and managed control structure.

## 2.1 Membership in RECS

Before trading can start, the owner of the production device has to become a member of RECS. The owner has to be registered at the RECS secretary web site and pay the registration fee. Moreover, the owner has to pay the membership fee to the Finnish Team. The Finnish Team co-ordinates the RECS activities in Finland.

## 2.2 Audit of production device

The production device shall be audited by an accredited auditing company. In Finland, auditing has been performed by SFS Sertifiointi Oy. SFS Sertifiointi writes an auditing report. The report contains general information on the production unit, energy measurement arrangements, account of ownership of the plant, and the owner’s guarantee of selling the green property only once.

When Fingrid has received the report, the production device is registered in the RECS register and trading can take place.

## 2.3 Issuing

For every 1000 kWh of produced renewable energy, a RECS certificate is issued. This certificate takes the form of an electronic record. The record states what is being certified: the identification of the Issuing Body, the location of the production device, the technology used for the production of the renewable energy, and the time when the certificate was issued.

### 2.4 Ownership transfer/trade

Once a certificate has been issued, it can be traded. The member records the transfer of ownership in the Central Registration Database and retains all documentation related to the transaction.

### 2.5 Redemption

The owner of a certificate can redeem it (e.g.) to advertise its environmental performances, or to fulfil a purpose specific to that country or region (e.g. renewable obligation, tax exemption, etc). After redemption, the certificate can no longer be transferred or traded.

### 2.6 Control structure

The issuing and trading with RECS certificates takes place according to the rules set in the Basic Commitment (BC), which was developed by the international Association of Issuing Bodies (AIB).

Based on the BC, the AIB drew up a standard protocol to act as a framework for the national Issuing Bodies to develop their own Domain Protocols, in which the BC has been applied to a specific country. The Domain Protocol specifies in more detail how the rules of BC are fulfilled in each country. Each protocol has been reviewed by the members of the AIB for acceptability as a pre-condition of participation in the Test phase.

## 3 Software for RECS

The Nordic Transmission System Operators, TSOs (Fingrid in Finland, Svenska Kraftnät in Sweden, Statnett in Norway, Eltra and Elkraft in Denmark), developed together a web-based certificate register (RECSCMO) for the management of certificates. These five companies own and manage the software together.

RECSCMO was developed by the Finnish company Absolutions according to the specification prepared by the Nordic TSOs and the consultant company EdiSys. The project specification phase started at the end of the year 2000 and was finalised at the beginning of 2001. The first version of the software was taken into operation in June 2001 and the first certificates were issued in Finland on 5 July 2001.

The main topics in the implementation and planning of the system were as follows:

- special attention to functionality
- the idea is to create a pilot system
- the solution has to be implemented with low costs without compromising security issues
- the system has to be easy to use.

The system has five main functions:

1. The IB can register the RECS members of its domain in the system.
2. The IB can register the production devices in the system.
3. The certificates are issued to the system by sending the metering data on the production device.
4. The RECS member can transfer the certificates within the system by choosing the certificates to be transferred and the party to whom the certificates are transferred.
5. The certificates can be redeemed when they are used by changing the status of the certificate from transferable to redeemed. Once the certificate is redeemed, the system does not allow it to be transferred.

Moreover, the system has a different type of reporting function to the RECS member and to the IB. The IB can follow the actions taken by the member.

The general information regarding production devices and some statistical information are public and can be viewed on the web site. Access to more detailed information is restricted to the members of RECS.

The RECSCMO system is available at address https://www.recscmo.com. During the test phase, also communication and transfer of data between the Nordic RECSCMO and other European RECS registers were studied and tested.

Instead of developing their own registers, Austria and Italy have decided to use RECSCMO as the RECS register for their own domains.

## 4 Measuring data

Only green production is eligible to receive RECS certificates, the quantity issued reflecting the amount of net electrical energy generated as evidenced by meter readings adjusted by meter amendments and the outcome of any disputes.

The net electrical energy generation is the gross production minus demand of any generating auxiliaries and minus losses in the main generator transformers on the site of the production device.

For a RECS-registered production device using bio-mass as the source of energy, the certificates can only be issued for the share of the total generation that derives from bio-mass. The share is calculated based on the fuels used and their share of the production (MWh).

The owner of the production device is responsible for collecting the metering data according to the RECS principles. The metering data is based on hourly metered values. Generating auxiliaries can, however, be taken into account by using other metering values or appropriate correction factors. The owner of the production device sends the green share of production to Fingrid in EDI format. EDI was chosen to be used in the transfer of metering values, because EDI is widely used in Finland and in other countries in energy settlement.

The time series are sent to Fingrid monthly after the owner of the plant has made all necessary fuel and auxiliary energy calculations. Fingrid forwards the measuring values to the RECSCMO database monthly.

## 5 Statistical information

Today there are 16 RECS members in Finland, and altogether 97 production devices have been registered in their accounts. So far, 3,257,198 certificates (MWh) have been issued in Finland. The certificates are distributed between various production technologies in the following way:

- Wind-onshore 16,037
- Wind-offshore 2,539
- Hydro 702,865
- Biomass/Energy crops 16,372
- Biomass/Forestry/Agricultural waste 2,512,425
- Biomass/Municipal waste 5,982
- Biomass/Industrial waste 978

The figures below show the issued, transferred and redeemed certificates in each month. Finland has been very active in starting to use RECS. The share of Finnish members of all issued certificates is almost 50%.

The number of transferred and redeemed certificates is much lower than those issued. At the moment, the data is not therefore up to date.

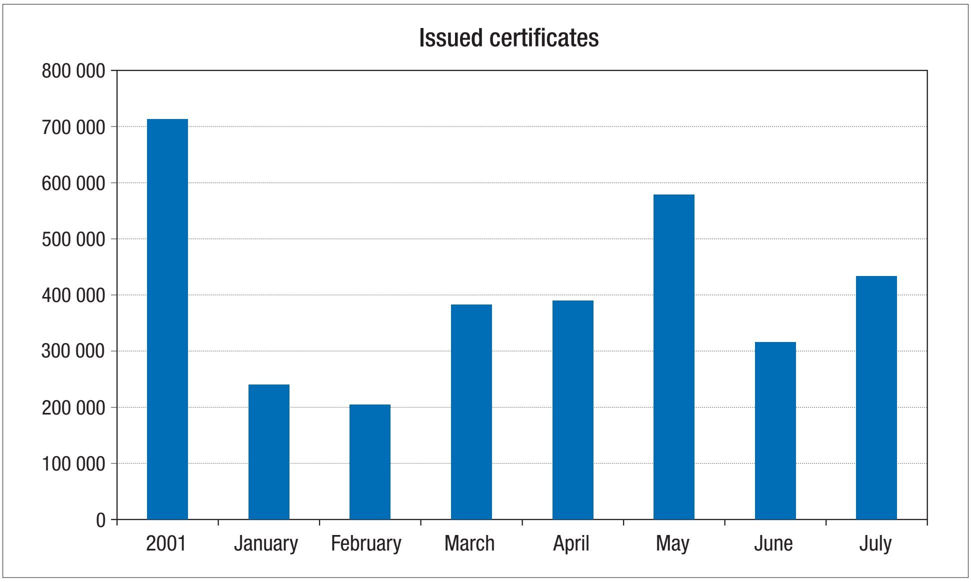


**Figure 2.** Issued certificates per month (12 September 2002).

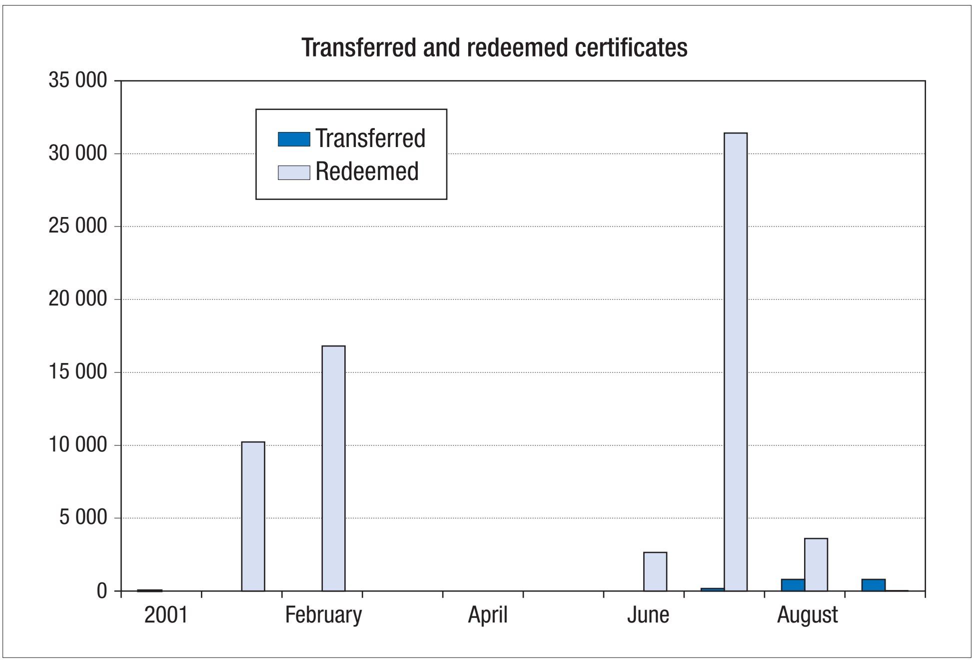


**Figure 3.** Transferred and redeemed certificates per month (12 September 2002).

## 6 Discussion

The implementation of RECS procedures in Finland has been carried out according to the original project plan.

The development and operation of the RECSCMO register has been carried out in a satisfactory manner. Small adjustments to the register during the test phase have been made when deemed useful.

The number of registered production devices and the number of issued certificates has been much higher than expected. By the end of 2002, there will be approximately six million issued certificates in Finland. This is mostly due to the opening of foreign certificate trade to the Netherlands.

If the RECSCMO register will be used after the RECS test phase in the stage of production, some development is needed to ensure the security and compatibility of the register. Also the transfer of certificates between European RECS registers has to be developed further and tested.

The RECS procedures used in Finland will also need some adjustment in the future.

## 7 Conclusions

The test phase of RECS shows that the procedures and the developed RECSCMO register are functioning technically as expected.

Because RECS is a voluntary system, the future of RECS depends on the members' willingness to continue. Some adjustments to the register and to the general RECS procedures would be necessary for the future.

# Information and Communication Technology (ICT) and Energy Economy
*Informaatioteknologian (ICT) vaikutus energiatalouteen*

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## Abstract

The objective of the study is to get an overview of the ICT effects on energy economy by studying published reports, articles and presentations. The main interest lies on USA, where most of the previous studies have been made. Based on the overview, effects of the ICT on Finnish energy economics are studied. Here, the most important industrial sectors, where detailed studies should be considered in future, are traced.

Energy intensity has decreased about one percent annually in USA during the 1990s. It is estimated that one third of the change has been structural, where economy has grown faster in non-energy intensive industries, such as information and communication technology (ICT) industry. The rest of the change has been due to the increase in energy efficiency of energy production, transmission and utilization.

The trends in US electricity consumption in residential and commercial sectors do not show any major changes due an increase in ICT technology. Estimates of electricity consumption in ICT vary from 2% to 8% in USA.

ICT has also indirect effects on energy consumption by e.g. e-commerce, telecommuting and dematerialization. Prediction and analyzing of these indirect effects is difficult, because complex cause-and-effect relationships of the society cannot be identified explicitly. Rebound and substitution effects of ICT can cancel possible energy savings.

The Finnish energy intensity has decreased in late 1990s annually over 3%. It seems that the high value added by the ICT-companies in the electrical products and manufacture sector has had a strong effect on the intensity.

Service business orientation in Finnish economy will increase the energy efficiency. With new business opportunities in ICT, the economy growth can be maintained at a high 2–4% level also in 2010–2030. Energy intensity might decrease annually by 2–3% in 2010–2030, due to transformation into service society.

## Tiivistelmä

Selvityksen tavoitteena on saada yleiskuva informaatioteknologian vaikutuksista energiatalouteen julkaistujen raporttien, artikkeleiden ja esitelmien avulla. Aiemmin julkaistusta materiaalista suurin osa käsittelee Yhdysvaltoja. Saadun yleiskuvan avulla arvioidaan mitä vaikutuksia informaatioteknologialla on Suomen energiatalouteen. Energian käytön alueet, joissa yksityiskohtaisemmat informaatioteknologian vaikutustarkastelut Suomessa saattaisivat olla tarpeen, on selvitetty.

Energiaintensiteetti on vähentynyt noin prosentin vuosittain 1990-luvulla Yhdysvalloissa. On arvioitu, että noin kolmasosa tästä muutoksesta on rakenteellista, jolloin talous on kasvanut enemmän ei-energiaintensiivisillä teollisuuden aloilla kuten informaatio- ja tietoliikenneteollisuudessa. Loput muutoksesta on aiheuttanut tehokkuuden lisääntyminen energian tuotannossa, siirrossa ja käytössä.

Informaatioteknologian yleistyminen ei ole muuttanut merkittävästi yksityisen ja kaupallisen sektorin sähkön kulutusta Yhdysvalloissa. Arviot informaatioteknologian osuudesta sähkön käytössä vaihtelevat kahdesta kahdeksaan prosenttiin.

Informaatioteknologialla on myös epäsuoria vaikutuksia energian kulutukseen esim. sähköisen kaupan, etätyön ja dematerialisaation kautta. Näi-

den epäsuorien vaikutusten ennustaminen ja analysointi on vaikeaa, koska yhteiskunnan kompleksisia syy- ja seuraussuhteita ei pystytä tunnistamaan eksplisiittisesti. Informaatioteknologian aiheuttamat rebound- ja korvautumisilmiöt voivat vähentää energian säästöpotentiaalia.

Suomessa energiaintensiteetti on vähentynyt 1990-luvun lopulla vuosittain yli kolme prosenttia. Näyttää siltä, että informaatio- ja tietoliikennealan yritysten menestys sähkö- ja konetekniikan toimialalla on vaikuttunut merkittävästi intensiteettiin.

Suomen taloudessa tapahtuva palvelusektorin kasvu lisää energiatehokkuutta. Informaatioteknologian avulla kansantalouden kasvu saadaan pidettyä korkealla 2–4 prosentin tasolla myös vuosina 2010–2030. Energiaintensiteetti voisi tällöin vähentyä vuosittain 2–3 prosenttia johtuen pääosin palveluliiketoiminnan kasvusta.

## 1 Introduction

Energy intensity has decreased about one percent annually in USA during the 1990s. It is estimated that one third of the change has been structural, where economy has grown more in non-energy intensive industries, such as information and communication technology (ICT) industry. The rest of the change has been due to increase in energy efficiency of energy production, transmission and utilization.

The present trend is forecasted to continue. It is possible that present economy forecasts may overestimate the future energy consumption and underestimate the growth of economy. It has also been estimated that ICT industry and use of ICT in various applications will increase the electricity consumption and at the same time environmental effects.

Information and communication technology is a cornerstone in dematerialization of the society. However, the dematerialization requires a change in human behavior and social innovations, besides the ICT development. Rebound effects of ICT should also be considered, where the environmental burden of society decreases less, or even increases, although the burden in activity in question decreases due to ICT. Examples of rebound effects can be found in telecommuting and paperless office.

The objective of the study is to get an overview of the ICT effects on energy economics by studying published reports, articles and presentations. The main interest lies on USA, where most of the previous studies have been made.

Based on the overview, the effects of the ICT on Finnish energy economics are studied. Here the most important industrial sectors, where detailed studies should be considered in the future, are traced.

By scenario approach, effects of ICT on Finnish energy economy in the future can be evaluated. The problem in evaluation of effects lies in the widespread use of ICT in a different kind of applications and industries, where the direct and indirect effects merge and present statistics do not have proper contribution in evaluation.

## 2 Recent trends in the U.S. energy intensity

Energy intensity, i.e., the ratio of energy consumed to unit of gross domestic product, is an indicator of the total energy efficiency of the national economy. During the internet era (1996–2000) the U.S. energy intensity has decreased on average 3.4% annually, whereas the annual drop during the oil crisis era (1973–1986) was averaging only 2.6%.

The unusual trend in energy intensity depicted in figure 1 can be explained by the exceptional growth of the “new economy”. From 1996 to 2000 the GDP has increased annually on average 4% while the U.S. energy consumption has experienced only 1% annual gain. The major trend of the internet era, the increasing use of the information and communication technology (ICT), seems to have generated significant economic growth without a major increase in the total energy consumption.

The recent improvements in U.S. energy intensity can be divided into structural and efficiency gains.

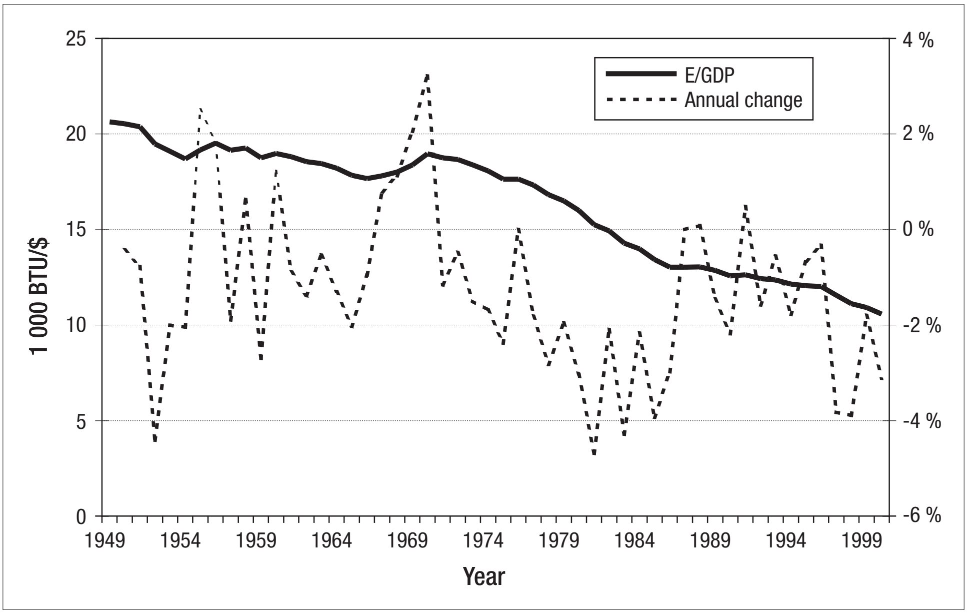


**Figure 1.** The U.S. energy intensity (E/GDP) from 1949 to 2000 and the annual percentual growth (EIA 2001a).

The structural effect of the ICT on energy intensity is based on the more rapid economic growth of the less energy-intensive information technology sector compared to the more energy-intensive traditional industry sectors. The non-structural improvements are based on the direct and indirect effects of the ICT on the society and economic system.

In a U.S. Environmental Protection Agency (EPA) study (Boyd and Laitner 2000), the recent decrease in energy intensity is divided into changes in electricity intensity and non-electric intensity. During the internet era the electricity intensity improved mainly subject to efficiency gains, whereas in 1997 and 1998 the non-electric intensity dropped 6% annually, half of the change due to sectoral shifts in economic activity. However, the contribution of ICT cannot be verified. It should be noted that in the EPA study, the non-electric energy does not include transportation, and the effect of weather on energy intensity is found insignificant.

In another study (Murtishaw and Schipper 2001) the changes in energy intensity are examined by dividing U.S. energy consumption into several sectors including, e.g., transportation, residential and manufacturing. The structural change, especially the strong growth of the ICT industries, is considered as the most significant reason for the decreasing energy intensity. Also, some energy-consuming activities, such as vehicle-kilometers and heated residential floor area, have not increased as rapidly as GDP. The study finds improvements in energy efficiency to be merely a minor factor and also argues that the effect of ICT on efficiency cannot be verified from the statistics. However, the changes in energy-consuming activities could be based on the indirect effects of ICT on the economic system.

Even if the ICT affected the energy intensity merely via sectoral shifts, the continuity of the recent trend can cause the estimates of future energy consumption to be overrated. The U.S. energy officials have reacted to the decreasing energy intensity and have set an estimate of 1.5% (EIA 2001b) as the annual drop in energy intensity through year 2020. However, ICT is not mentioned as the reason for the re-estimation.

## 3 Electricity consumption of the ICT and the internet

The sectoral shift due to the strong growth of the ICT sector and the indirect effects of ICT on economy are possible, because use of computers and internet has spread like a wildfire in the modern society. From the energy consumption point of view, this development leads to a massive information technology infrastructure, which can become a major consumer of electricity.

The year 2000 estimate of the number of PC units in U.S. is over 130 million (ADL 2002). Moreover, the network infrastructure of the internet and the intranets consists of numerous electrical appliances such as routers, servers, etc. However, the recent trends of U.S. electricity end use depicted in figure 2 do not reveal any major changes of electricity consumption in residential and commercial sectors in the 1990s, which is the era of computerization.

In 1999 a controversy over electricity consumption of the information technology was caused by a study (Mills 1999), which suggested that internet alone uses 295 TWh of electricity, i.e., 8% of the total U.S. consumption. In the study only the computers and appliances connected to the internet were included, and on-line time of 12 hours per week was used. Moreover, by adding up the unnetworked computers and devices, the share of ICT is calculated to be 13% of the total electricity consumption.

However, in a memorandum (Koomey et al. 1999) by Lawrence Berkeley Laboratory (LBNL) these claims were responded and corrected estimates presented. The overestimations in (Mills 1999) are based mainly on too high power consumption values used in calculations. The corrected estimate of the electricity consumption associated with internet is stated by LBNL as 36 TWh.

LBNL has also presented in (Kawamoto et al. 2001) estimates for the electricity consumption of the entire U.S. ICT infrastructure. Computers and other devices use 74 TWh, i.e., 2% of the total consumption, of which commercial share is 71% and residential only 12%. The most recent study (ADL 2002) suggests computers and appliances in commercial sector using 97 TWh (3% of total use) in year 2000. The main reasons for these reasonable consumption values seem to be decreasing power demands of electrical devices and the saturation of computers in offices.

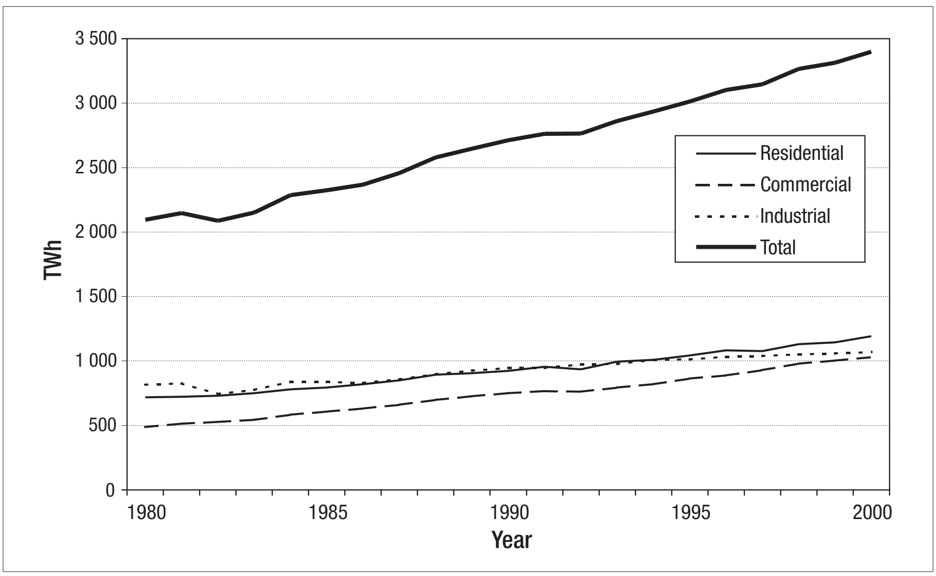


**Figure 2.** The total electricity end use in U.S. from 1980 to 2000 and the electricity used by residential, commercial and industrial sectors (EIA 2001a).

# 4 ICT and energy consumption

Information technology can affect the energy economy also otherwise than via sectoral shift or electricity use of the computers. The use of high technology in economic activities can improve energy efficiency, although usually cost-efficiency being the major incentive. Thus, development of these methods depends on energy prices.

In the industrial sector ICT can be used, e.g., to optimize and control manufacturing processes, but it is hard to point out the direct effect of ICT on improved energy efficiency. In the commercial sector so called intelligent systems monitor the state of business buildings and control consequently lighting, heating and air-conditioning. These systems can produce even 25% energy savings, but low energy prices may reduce even such investments (Romm 1999).

The magnitude of these direct effects on energy consumption can be evaluated by doing technical measurements and calculations, but ICT affects energy consumption also indirectly. A society is a chaotic and complex system with numerous indirect causal connections. When a new technology changes human behavior in energy-consuming activities, cumulative effects can be surprising. The prediction and analyzing of these indirect effects is difficult, because complex cause-and-effect relationships of the society cannot be identified explicitly (Allenby 2000). Also, several rebound and substitution effects of ICT can cancel possible energy savings.

## 4.1 E-commerce

In e-commerce the vendor and the client agree the transaction of a product or a service via internet. Nowadays the contribution of e-commerce to the total trade is small, but the share is estimated to be 7% in 2004 (Romm 1999). Moreover, e-commerce is mostly substituting regular trading, therefore indirect effects of e-commerce on energy use can be significant.

If the client purchases the product on-line instead of in a store, the vendor avoids heating, lighting and air-conditioning of the building. Also, the transition from traditional trade to e-commerce affects the energy-intensive construction industry due to the decreasing demand of business premises. It is estimated in (Romm 1999) that predicted growth of e-commerce would lead to 1.5 billion square feet of unused floor area in commercial buildings. It is also calculated that ratio of energy required per book between traditional book store and e-commerce is 16/1 (Romm 1999). It should be noted that analyzing the effects of ICT on buildings is quite difficult due to the lag in statistics.

The utilization of e-commerce in business-to-business (B2B) trading has great potential to reduce inventories, and it is estimated that maintenance of one billion square feet of warehouses can be avoided due to e-commerce in 2007 (Romm 1999). B2B e-commerce is based on information systems, which are used by companies to place orders to subcontractors on the basis of on-line orders by customers. Such an electronic cooperation between companies lowers inventory to sales ratio and also energy consumption.

From the customer point of view, on-line shopping substitutes for driving to the store. However, the product usually must be shipped to the customer even via air freight which can cancel energy savings of e-commerce. Nevertheless, utilization of ICT in optimizing the freight routes can make e-commerce more energy efficient than a traditional trip to a mall.

## 4.2 Telecommuting

Internet and communication systems enable telecommuting, i.e., working at home or elsewhere instead of in office. Telework is beneficial to the employee, employer and environment; home-based work is more comfortable for the employee and no time is wasted on commuting, the employer can reduce office space, and energy consumed by car trips to work and maintenance of offices can decrease.

A worker is estimated to consume 4500 kWh less electricity per year in home office than in traditional workplace (Romm 1999). Also, it is predicted that with a recent growth rate of home-based businesses, 2 billion square feet of offices can be made redundant in year 2007 (Romm 1999). Telecommuting has great potential to reduce energy consumed by transportation, but verifying this effect from statistics is difficult due to the briefness of the internet era. It should also be noted that telecommuting might increase other car trips and cause urban sprawling and therefore longer driving distances.

### 4.3 Dematerialization

Due to the applications of ICT, information no more has to be stored, transferred or collected in physical form. Therefore, the dematerialization of information has great potential to reduce manufacturing of the materials used to store information, e.g., very energy-intensive paper production. However, paperless office has not come true, but consumption of office paper has increased regardless of dematerialization. Nevertheless, the manufacturing of newsprint has decreased due to on-line news (BCG 1999).

## 5 ICT and Finnish energy economy

The Finnish energy intensity has fluctuated greatly during the past decades, mainly due to the major changes in GDP as depicted in figure 3. The strong recession and economic boom of the 1990s caused energy intensity to drop only on average 0.8% annually. However, during the internet era the annual decrease has been 3.3% and in 2000 the energy intensity dropped 6.6% due to the decrease in energy use.

The industrial energy intensity has also decreased in the late 1990s, which is caused by unusual growth of value added, whereas growth rate of energy consumption is similar to the 1980s. The effect of sectoral shift is to be revealed by examining the electricity intensities of the four main electricity-consuming industrial sectors. The machinery and electrical products manufacture has experienced major decline in electricity intensity, whereas the remaining sectors only have minor decreases during the ICT era as seen in figures 4 and 5. Also, the industrial electricity intensity has

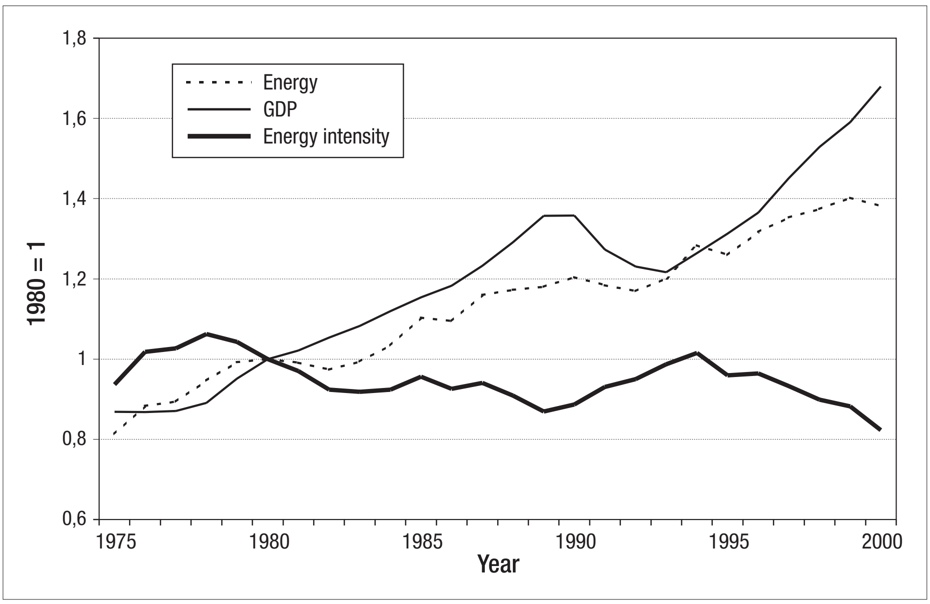


**Figure 3.** The Finnish energy consumption, gross domestic product (GDP) and energy intensity from 1975 to 2000 proportional to year 1980.

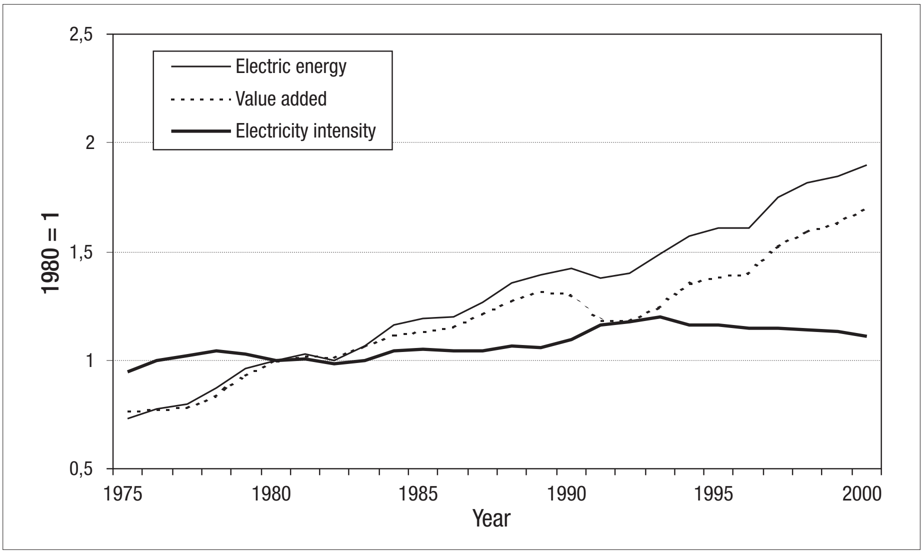


**Figure 4.** The Finnish electricity consumption, value added and electricity intensity from 1975 to 2000 proportional to year 1980 not including the machinery and electrical products manufacture.

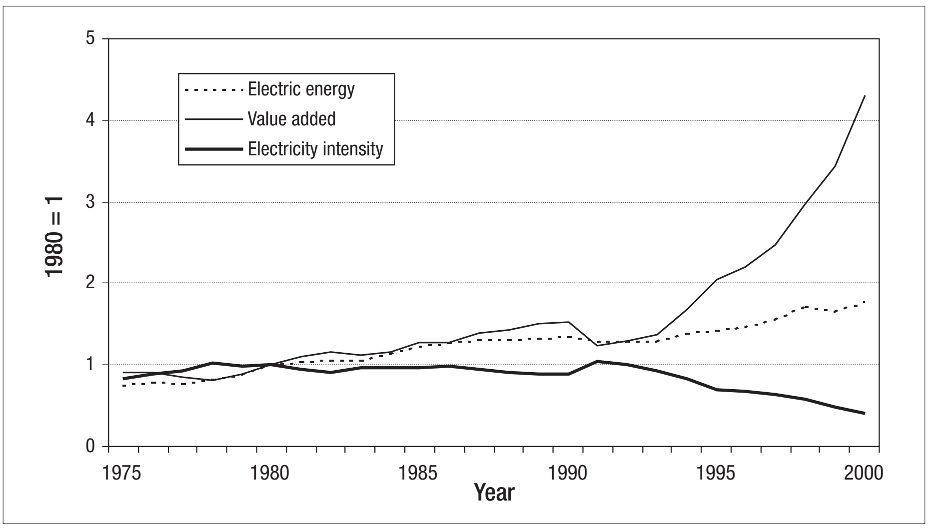


**Figure5.** The Finnish electricity consumption, value added and electricity intensity in the machinery and electrical products manufacture form 1975 to 2000 proportional to year 1980.

hardly a decreasing trend, if the machinery and electrical products manufacture sector is excluded. It seems that the high value added by the ICT-companies in the electrical products and manufacture sector affects strongly the electricity intensity.

As was stated earlier, ICT and internet era have not caused any considerable change in the U.S. electricity consumption trends. Finland is one of the leading countries subject to computers and internet connections per capita. When analyzing the Finnish electricity consumption, electric heating should be excluded from the statistics due to the fluctuation of weather conditions. However, the electricity consumption statistics without electric heating do not show any rising trend in the ICT era.

In (Heiskanen et al. 2001) some of the indirect effects of ICT on energy use are studied. The energy consumed by road transportation has increased in the 1990s clearly less than in the 1980s, and the recent trend of passenger transportation is more or less level. However, reasons behind this development are related rather to saturation of the motor vehicle stock than to e-commerce or telecommuting.

E-commerce is not as common in Finland as in the USA, and usually products purchased on-line are shipped from abroad. In (Heiskanen et al. 2001) energy effects of e-grocery are studied. It is estimated that in 2010 the share of on-line grocery is 5–10% and with 10% share 7% of the energy used by production chain and customer traffic can be saved. However, the potential of energy savings depends on the length of the delivery routes.

## 6 Future effects of ICT on Finnish energy economy

Finland has not been very much of services society. Finnish private services account only for 40% of GDP; which is about 10% less than EU average. However, Finland has been swiftly transforming into an information society, which includes a large amount of services. In future the service sector shall account for at least 50–60% of GDP in Finland. Moreover, industrial sectors shall include more and more services in the form of after sales, monitoring and maintenance functions.

Increasing service orientation will increase the energy efficiency of Finnish society. This trend is the main contributor in energy efficiency in the future, where ICT is the main driver for new business opportunities. With new business opportunities the Finnish economy growth can be maintained in high 2–4% level also in 2010–2030. Energy intensity might decrease annually by 2–3% in 2010–2030 due to transformation into service society.

ICT effects on energy economy are somewhat controversial. On one hand dematerialization can decrease energy utilization e.g. in paper industry, and on the other hand ICT might increase energy utilization through rebound effects.

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# Reducing Carbon Dioxide Emissions of Transport in Finland

*Liikenteen hiilidioksidipäästöjen vähentämismahdollisuudet Suomessa*

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## Abstract

In Finland the goal of reducing carbon dioxide emissions of transport has been set to reduce the emissions to 1990 level by the years 2000–2012. Approximately 64% of the carbon dioxide emissions of transport are caused by passenger transport and 36% by goods transport. Almost two thirds of the emissions are due to the long distance regional traffic, which also includes the emissions of water and air traffic. According to the emission forecast defined in the national LIPASTO-database, the amount of carbon dioxide emissions will by the year 2020 be approximately 9% greater than in 1990, if present development of transport demand, and of vehicle and fuel technology will continue.

Several measures to reduce carbon dioxide emissions have been analyzed in this study. In addition to the effect on carbon dioxide emissions, the applicability and feasibility of the measures have been assessed. The emissions and mileage of passenger and goods transport have in this study been divided into source areas, in order to be able to make an inventory of the emissions by source, to assess the effects of the measures, and to allocate the measures effectually.

The assessed measures have been mainly allocated to the modes and source areas where the emissions are greatest. The studied measures include different means of transport pricing, legislative measures, development of vehicle technology, promoting public transport, decreasing the traffic congestion, development of transport system, and changes of attitudes and life styles.

Among the most efficient measures to reduce carbon dioxide emissions would be increasing the fuel price, decreasing the annual tax of diesel passenger cars, promoting economical driving style, and adding bio-fuel components to conventional gasoline and diesel fuels. Also promoting railway transport and increasing the maximum total weight of articulated trucks to 70 or 80 tons would decrease carbon dioxide emissions notably. The most efficient measure of studied public transport means was the development of light rail systems in urban areas.

## Tiivistelmä

Suomessa liikenteen hiilidioksidipäästöjen vähimmäistavoitteena on pidetty päästöjen määrän palauttamista vuoden 1990 tasolle vuosiin 2008–2012 mennessä. Noin 64 % Suomen liikenteen hiilidioksidipäästöistä on peräisin henkilöliikenteestä ja noin 36 % tavaraliikenteestä. Lähes kaksi kolmasosaa henkilöliikenteen hiilidioksidipäästöistä on peräisin pitkämatkaisesta eri seutukuntien välisestä liikenteestä, johon kuuluvat myös laiva- ja lentoliikenteen päästöt. Liikenteen hiilidioksidipäästöjen perusennusteen mukaan hiilidioksidipäästöjen määrä on vuonna 2020 noin 9 % suurempi kuin vuonna 1990, jos nykyisenkaltainen kehitys liikenteen kysynnässä sekä ajoneuvo- ja polttoainetekniikassa jatkuu.

Tässä tutkimushankkeessa on selvitetty erilaisten liikenteen hiilidioksidipäästöjä vähentävien keinojen vaikutusta liikenteen hiilidioksidipäästöihin ja arvioitu toimenpiteiden soveltuvuutta hiilidioksidipäästöjen vähentämistavoitteiden kannalta. Päästöjen inventointia, toimenpiteiden vaikutusten arviointia ja toimenpiteiden kohdentamista varten liikenne on tutkimuksessa jaettu liikennemuodoittain lähdealueisiin, jolloin on voitu melko yksityiskohtaisesti tutkia kunkin keinon vaikutusten laajuutta. Tutkitut toimenpiteet on kohdennettu pääosin niihin liikennemuotoihin ja niille lähdealueille, joissa päästöt ovat suurimmat. Tutkimuksessa on

tarkasteltu taloudellisen ohjauksen, lainsäädännöllisten keinojen, ajoneuvotekniikan kehittymisen, joukkoliikenteen edistämisen, liikenteen sujuvuuden parantamisen, kuljetusjärjestelmien kehittymisen sekä asenteiden ja elämäntapojen muuttumisen vaikutuksia liikenteen hiilidioksidipäästöihin.

Laskennallisesti tutkituista toimenpiteistä liikenteen hiilidioksidipäästöjä vähentäisivät eniten polttoaineen hinnan korottaminen, moottoriajoneuvoveron eli ns. dieselveron alentaminen, taloudellisen ajotavan yleistyminen ja biokomponenttien lisääminen polttoaineisiin. Myös rautatiekuljetusten suosiminen ja ajoneuvoyhdistelmien suurimman sallitun kokonaismassan nostaminen vähentäisi hiilidioksidipäästöjä melko paljon. Joukkoliikenteen keinoista tehokkain on kaupunkiseutujen raideliikenteen kehittäminen.

## 1 Introduction

Approximately 18% of the total carbon dioxide emissions in Finland are caused by the transport sector. EU has accepted to aim to reduce the greenhouse gas emissions by 8% compared to 1990 level by the years 2008–2012. National goals for reducing the emissions have been set separately taking into account the local possibilities to reduce emissions and increase energy efficiency. In Finland the possibilities to reduce the amount of carbon dioxide emissions have been evaluated to be limited due to the already high level of bio-energy use and combined production of electricity and heat, and relatively efficient energy use in industry, housing and transport. Finnish national goal was in EU set to restore the emissions to 1990 level by the years 2008–2012. (Kulmala and Kallberg 2002, VTT 2001)

According to Finnish national emissions database for transport (LIPASTO) the amount of carbon dioxide emissions will increase by 9% during the years 1990–2020, if present development of transport demand and vehicle and fuel technology continues (VTT 2001). Figure 1 presents the relative development in carbon dioxide emissions in 1990–2001 and a forecast for 2002–2020. Several measures of reducing the carbon dioxide emissions have been analyzed in this study. In addition to carbon dioxide emission effects, also the applicability and feasibility of the measures have been assessed.

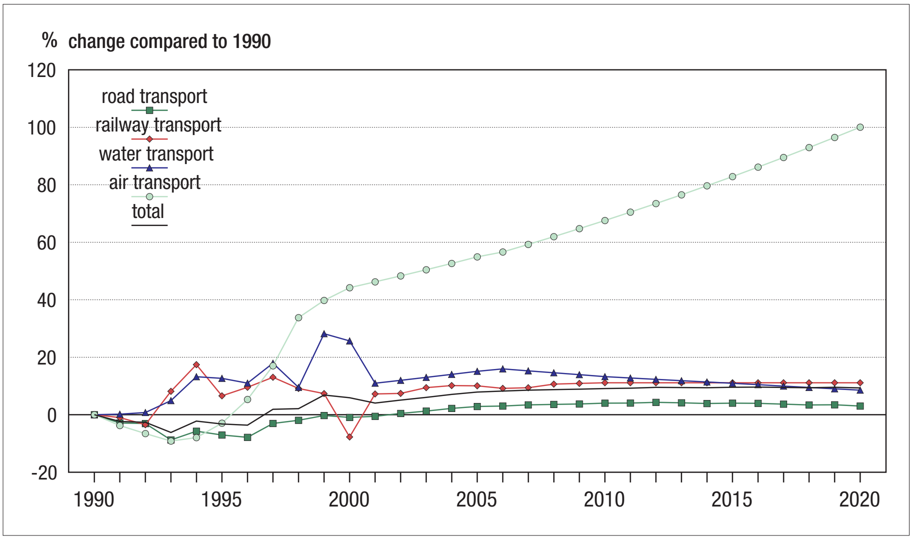


**Figure 1.** The development of carbon dioxide emissions of transport in 1990–2001 and a forecast for 2002–2020 compared to the base year 1990.

## 2 Methods

### 2.1 Emissions by mode and source area

The transport demand and carbon dioxide emissions have been divided into modes of transport and into geographical source areas in order to be able to inventory the emissions, to assess the effects of measures, and to allocate the measures according the source areas. The measures have been mainly allocated to the modes and source areas that have the greatest carbon dioxide emissions.

Figure 2 presents the carbon dioxide emissions divided into passenger and goods transport and into geographical source areas in passenger transport. Almost two thirds of the emissions are related to regional long distance traffic, including also water and air traffic.

Most of the carbon dioxide emissions in passenger transport are caused by passenger cars. Figure 3 shows the emissions divided into passenger transport modes. The relative share of passenger car traffic will decrease during the forthcoming decades, although the mileage of passenger car traffic has been estimated to increase. At the same time the emissions of air traffic will grow significantly. The emissions of passenger traffic have been evaluated to decrease by 6% during 1999–2020.

In the goods traffic sector approximately 60% of the emissions originate from road transport. Almost 35% of the emissions are caused by cargo vessels. The amount of carbon dioxide emissions in goods transport has been forecasted to increase by 11% during 1999–2020.

### 2.2 Measures to reduce the emissions

The studied measures to reduce carbon dioxide emissions are connected to transport pricing, legislation, development of vehicle and motor technology, promoting public transport, decreasing the congestion of traffic, developing the freight transport systems, and changes of the attitudes and life styles. The study period is 1999–2020. The measures to reduce carbon dioxide emissions were compiled in a comprehensive literature survey. Al-

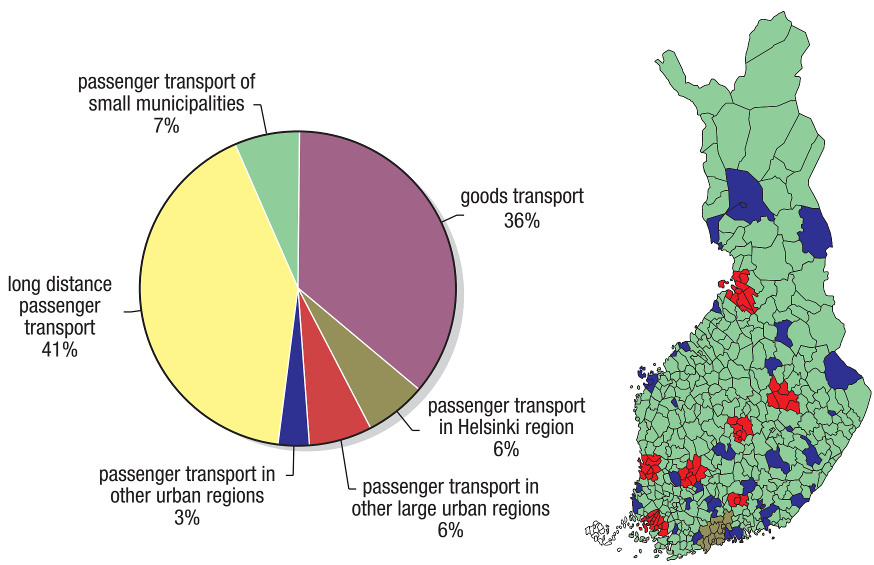


**Figure 2.** Carbon dioxide emissions divided into goods and passenger transport and into geographical source area.

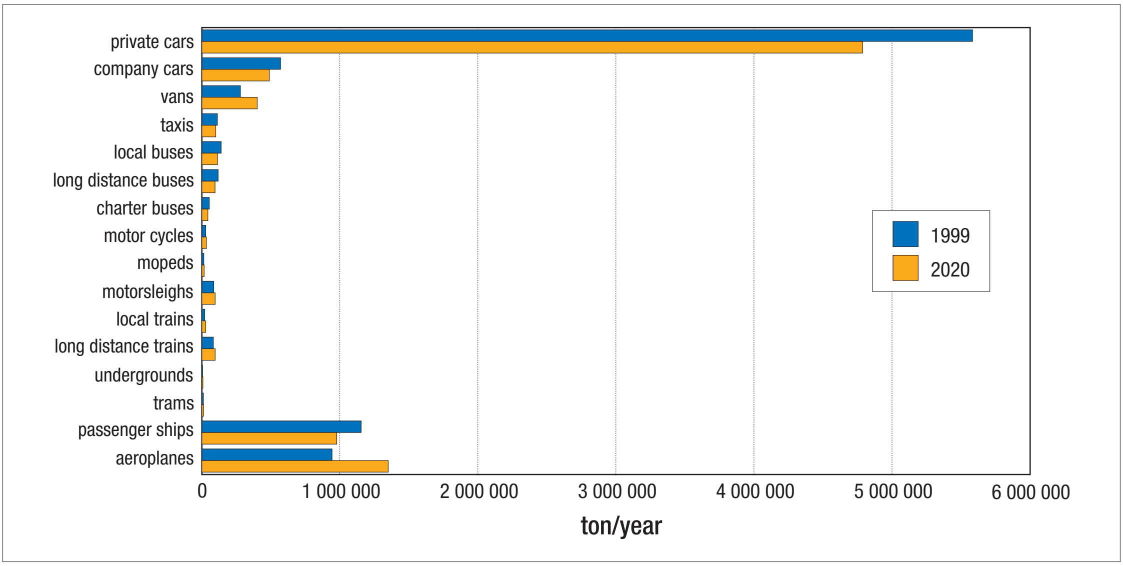


**Figure 3.** Carbon dioxide emissions of passenger transport in 1999 and forecast for the year 2020.

together 37 measures have been presented, of which 15 were chosen into further analysis. Table 1 presents the studied measures and the basic calculation assumptions. The measures are partly overlapping and their effects cannot therefore be added up. For example increasing the fuel prices affects driving style and transfers demand to fuel-efficient vehicles, which have also been studied as separate measures.

Most of the measures are allocated on road transport sector, because road transport has a dominant role of carbon dioxide emissions also during the forthcoming decades. The development of vehicle technology has been included in the pricing measures influencing consumer behaviour – transferring the demand towards more fuel-efficient vehicles.

**Table 1.** Studied measures to reduce carbon dioxide emissions.

| Measure | Description | Mechanism |
|---|---|---|
| increasing gasoline and diesel fuel price for passenger cars | • fuel price increases by 25%<br>• fuel price increases by 50% | Price increase reduces mileage and affects driving style on the short run. On the long run price increase affects choices of vehicle and household ocation. |
| passenger car purchase tax differentiation | • purchase tax depends on the carbon dioxide emissions of the vehicle | Tax reform decreases the retail prices of fuel-effective cars and increases the price of much fuel consuming cars. |
| decrease of annual tax of diesel vehicles | • annual tax of diesel driven passenger car is decreased | The share of diesel driven passenger cars increases in the vehicle fleet. |
| introduction of biofuel components | • bio-ethanol is added to conventional gasoline (E10) and biodiesel (vegetable oil esters) to diesel fuel | Life cycle emissions of carbon dioxide decrease, because carbon dioxide consumed during the cultivation of biomass can be taken into account. |

… Table 1. continues

| Measure | Description | Mechanism |
|---|---|---|
| reduction of public transport fares | • local bus fares decrease by 20% and long-distance public transport fares by 30% | Increases the willingness to use public transport. |
| promoting employer paid public transport tickets | • taxation value of employer paid public transport tickets is decreased and ticket type is actively marketed to employers and employees | Increases the willingness to use public transport. |
| increasing public trans-port priorities in urban areas | • public transport is given priorities at traffic signals and main streets by separate bus lanes in largest urban areas | Increases public transport service level by reducing ride times, reduces fuel consumption of bus traffic by decreas-ing number of stops due to traffic signals and congestion. |
| development of urban light rail systems | • light rail system is developed at metropolitan area and introduced in other large urban areas | Increases public transport supply, decreases public transport ride time, reduces energy consumption of public transport. |
| development of traffic signal control systems | • traffic signals are controlled aiming to minimize the number of stops instead of minimizing the amount of delays | Reduces fuel consumption by decreasing the number of stops. |
| increasing the maximum total weight of articulated vehicles | • the maximum total weight of articulated vehicles increases from 60 tons to 70<br>• the maximum total weight of articulated vehicles increases from 60 tons to 80 tons | Decreases the total truck mileage. |
| increasing the load factor of trucks | • load factor increases and empty running decreases | Decreases the total truck mileage. |
| promoting rail freight transport | • part of goods transported by road are shifted to be transported by rail | Decreases the total truck mileage. |
| lowering speed limits | • existing speed limits on main roads are followed more accurately by ncreasing speed control systems<br>• winter speed limits are extended to obtain round-the-year | Decreases fuel consumption per km. |
| promoting economical driving style | • all drivers follow economical driving style<br>• 20% of passenger car drivers and 60% of bus and truck drivers follow economical driving style | Decreases fuel consumption per km. |

## 3 Effects on carbon dioxide emissions

The effects of the studied measures on the carbon dioxide emissions in 2020 are compared to the basic scenario presented in LIPASTO database. Basic scenario represents the present development, which has been assumed to continue during the next decades. It includes for example the predicted improvement of fuel-efficiency of passenger cars and the anticipated growth of transport demand.

The carbon dioxide emissions of transport are in the studied cases 0.5%–15% smaller than in the basic scenario in 2020. The most efficient measures to reduce carbon dioxide emissions are measures connected to fuel price and vehicle taxation. Also promoting the economical driving is an efficient method even without economical incentives. Figure 4 shows the effects of studied measures on the carbon dioxide emissions of the transport in 2020.

### 3.1 Increasing the fuel prices of passenger cars by 25% or 50%

Increasing the fuel price by 50% would decrease the carbon dioxide emissions by 8–15% on the long run. Increasing the price by 25% would decrease the emissions by 4–7%. The effects have been calculated on each source area by using price elasticities. Fuel price elasticities have in the short term studies been observed to vary between –0.15 and –0.5 and in the long term studies between –0.3 and –0.9 (Swahn et al. 1994, Goodwin 1992). Increase in the fuel price affects travel behaviour in several ways: the reduced mileage is due to shorter trips, choosing other modes than car, and increased car pooling. Price also affects awareness of economical driving style and increases the demand for fuel-efficient vehicles. In the long run fuel price affects household and choices of work site location. However, effects of increasing fuel prices are socially unsustainable, and the effects are not fairly distributed among different social groups and regions. Price increase affects also areas, where there are not available any alternative more fuel-efficient modes for passenger cars. Therefore the effects should be considered primarily from the viewpoint of social sustainability and equity of mobility.

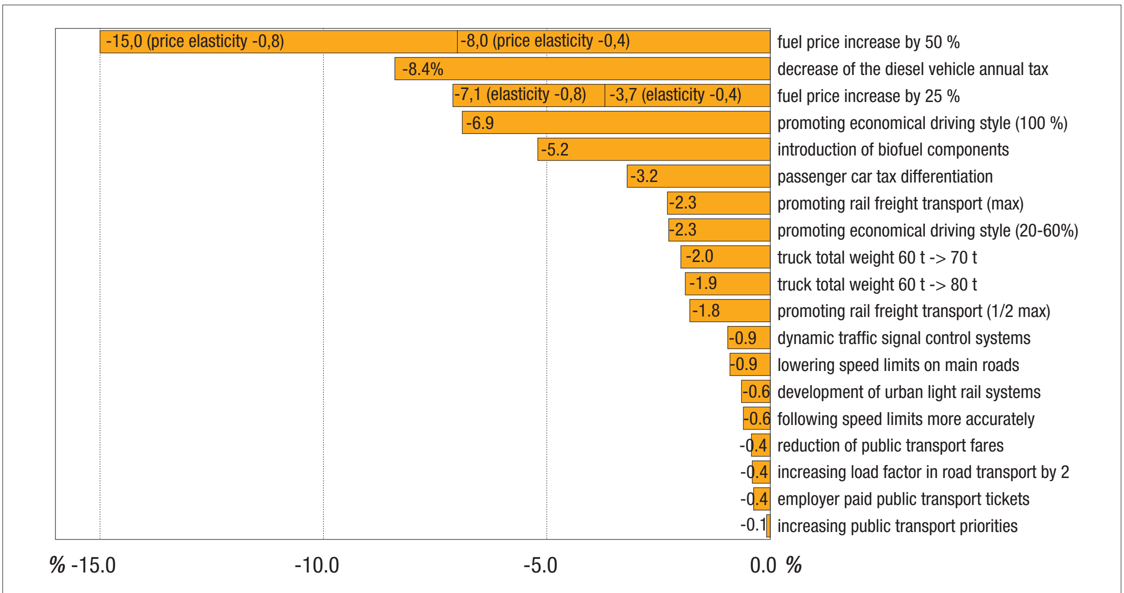


**Figure 4.** The effects of studied measures on the carbon dioxide emissions of transport compared to the base scenario in 2020.

### 3.2 Decrease of the annual tax of diesel vehicles

Reducing the annual tax of diesel driven passenger cars would increase the share of diesel cars in the vehicle fleet significantly. If the consumers would prefer the same vehicle size as previously, the carbon dioxide emissions would decrease by 4%, due to the better fuel-efficiency of diesel technology. If the demand would be guided to the most fuel-efficient quartile of the same vehicle size class, the carbon dioxide emissions would be 8% smaller than in the basic scenario. An increasing amount of diesel vehicles would increase the amount of nitrogen oxide and particulate matter emissions, if the specific emissions of diesel vehicles would not decrease more than in the basic forecast during the next decades. Therefore, large-scale introduction of diesel driven passenger cars would have a negative impact on urban air quality.

### 3.3 Passenger car purchase tax differentiation

Consumer preferences concerning new passenger cars can be affected by modifying the vehicle purchase tax in order to increase the price of less fuel-efficient vehicles and decrease the price of fuel-efficient vehicles. The tax is at the present determined on the basis of the import price. A taxation system that would take into account the motor power, weight, engine size or fuel consumption, would affect the consumer preferences more efficiently than the present taxation structure. In this measure the purchase tax would be adjusted moderately to guide the demand to the most fuel-efficient quartile of the same vehicle size class as in present taxation system. Thus, it would not affect the vehicle fleet size very much, but would increase the demand of fuel-efficient vehicle types. The amount of carbon dioxide emissions would with this measure be 3% smaller than in the basic scenario. Differentiation of purchase tax is a feasible measure, because it would not affect household transport expenses unevenly and would not necessarily change the amount of collected taxes.

### 3.4 Bio-fuel components of conventional fuels

Adding small amounts of biofuel components to conventional gasoline and diesel fuel does not demand modifications to conventional motor or fuel systems. Biocomponents could thus be introduced without wide-ranging alterations of existing vehicle fleet. Ethanol can be added to gasoline up to 10% concentration without motor modifications (Ikonen et al. 2000). Biodiesel could be added to diesel fuel to a greater extent without motor or fuel system modifications, but due to the high manufacture costs and poor availability it is not very likely that the concentration would be high. The assumption in the calculations was, that the concentration of biocomponents would be 10% in both gasoline and diesel fuel. The amount of carbon dioxide emissions would decrease by 5% with these assumptions. Biocomponents are relatively expensive, and the increased costs would presumably be paid partly by consumers and partly by state. This measure would be easily acceptable to individuals, if the price increase is moderate, since it does not require any behavioural changes. It can also be implemented together with other measures without loosing its efficiency.

### 3.5 Promoting economical driving style

Promoting economical driving style would decrease the carbon dioxide emissions by 3–7% compared to the basic scenario. In the more efficient scenario almost all drivers have adopted the economical driving style, which would require all drivers to be educated to economical driving and introduction of technical device guiding the driver's driving style. In the more moderate scenario 20% of passenger car drivers and 60% of truck and bus drivers have adopted the economical driving style. Willingness to drive economically usually increases, if fuel price is increased. Also positive incentives to promote economical driving should be studied.

### 3.6 Improving public transport service level

Measures improving public transport service level or reducing public transport fares have relatively small effect on the total amount of emissions. The amount of carbon dioxide emissions is less than 1% smaller than in basic scenario in all the studied public transport measures. Locally their effects can be significant – for example employer paid public transport ticket system would decrease the carbon dioxide emissions by 2.5–3.5% in large urban regions, although the effect on national level would be less than 0.5%. The measures of promoting public transport have many other positive impacts, for example impacts on modal split, exhaust gases and urban air quality. The most efficient public transport measure for reducing carbon dioxide emissions would be development of light rail systems in the large urban areas, requiring relatively large investments.

### 3.7 Lowering the speed limits

The average speed influences the energy consumption also on main roads, which in Finland usually have a speed limit for 80 or 100 km/h. In winter a notable amount of roads have a winter speed limit for 80 km/h due to traffic safety reasons. Optimal speed for energy consumption would on the main road driving conditions be approximately 70 km/h (Rouwendahl 1996). Most of the passenger car drivers are speeding at the main roads, the average overspeed on main roads is 8–10 km/h (Kangas 2000). The studied measures concerning speed limits are more accurate follow-up of the speed limits and extension of the winter speed limit of 80 km/h to all-year limitation. Following up the present speed limit more accurately would reduce carbon dioxide emissions by 0.6 %, and both more accurate follow-up and extension of winter speed limits by 0.9 %. More accurate follow-up of speed limits would require more automatic and manual speed control systems. Also overspeed prevention devices should be introduced to be able to reduce speeds efficiently. Speed reduction measures can also be supported from traffic safety viewpoint. However, they are relatively difficult to be accepted by car users.

### 3.8 Measures of goods transport

The most efficient measures of freight transport are promoting the economical driving style and increasing the maximum total weight of articulated trucks to 70 or 80 tons from the present level of 60 tons. Especially the raw wood transports would benefit from the increased maximum weight. A 70-ton maximum weight is more fuel-efficient option than 80 tons, which would require an increase in the number of axles in the articulated trucks (Koskinen and Sauna-aho 2001). The increase of the maximum weight to 70 tons would decrease the amount of carbon dioxide emissions of transport by 2% compared to the basic scenario.

Also promoting of rail freight transport is a relatively efficient measure to reduce carbon dioxide emissions, but would require relatively large investments on rail infrastructure. Modal shift of 8% of truck ton kilometres to railway would decrease the carbon dioxide emissions by approximately 2% compared to basic scenario.

## 4 Conclusions

The feasibility and applicability of measures depends on the priorities and weighing of the selection criteria. For the public sector the most important criteria could be cost efficiency and suitability to transport policy. Many measures have both direct and indirect costs that can be distributed unevenly among different sectors of society. Most feasible measures to reduce emissions are acceptable and cost-efficient for individuals, business life and public sector.

As an example of different selection criteria, Table 2 presents three different measure packages, which have been chosen on the basis of cost efficiency for public sector, consumer preferences and air quality improvement in urban areas. The selection criteria rank the measures to completely different feasibility groups. Promoting economical driving, increasing the road transport load factor and promoting the employer paid public transport tickets are examples of measures that are relatively easily acceptable from the criteria of cost-efficiency, consumer welfare and air quality improvement. On the contrary, reducing the annual vehicle tax of diesel driven passenger cars would not be feasible from the viewpoint of cost efficiency and air quality. Also the increase of fuel prices would have relatively complicated economical consequences affecting several sectors of society.

**Table 2.** Measure packages chosen with criteria of cost-efficiency, consumer welfare and urban air quality improvement.

| | **Cost-efficient measures to public sector** | **Measures that do not effect consumer welfare significantly** | **Measures improving the urban air quality** |
|---|---|---|---|
| Description | Minimizing the costs of public sector. | Increasing or maintaining the possibilities of mobility, decreasing or maintaining the present transport costs. | Urban air quality goals are emphasized. |
| Most feasible measures | • extension of winter speed limits<br>• speed limits are followed more accurately<br>• increasing the load factor of trucks<br>• promoting employer paid public transport tickets | • increasing the maximum total weight of articulated trucks<br>• development of traffic signal control systems<br>• reduction of public transport fares<br>• promoting employer paid public transport tickets<br>• promoting economical driving style<br>• decrease of annual vehicle tax of diesel driven passenger cars<br>• passenger car purchase tax differentiation<br>• development of urban light rail systems<br>• increasing public transport priorities in urban areas<br>• promoting rail freight transport | • promoting economical driving style<br>• development of urban light rail systems<br>• promoting employer paid public transport tickets<br>• development of traffic signal control systems<br>• increasing public transport priorities in urban areas<br>• reduction of public transport fares |

… Table 2. continues

| | Cost-efficient measures to public sector | Measures that do not effect consumer welfare significantly | Measures improving the urban air quality |
|---|---|---|---|
| Relatively feasible measures | • increase of fuel price<br>• promoting economical driving style<br>• increasing the maximum total weight of articulated trucks<br>• passenger car purchase tax differentiation | • introduction of biofuel components | • increase of fuel price |
| Not acceptable measures | • development of urban light rail systems<br>• promoting rail freight transport<br>• decrease of annual vehicle tax of diesel driven passenger cars | • increase of fuel price<br>• extension of winter speed limits<br>• speed limits are followed more accurately | • decrease of annual vehicle tax of diesel driven passenger cars |

## Publications and reports made under the project


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# The Impact of Climate Change on Energy Management
*Ilmastonmuutoksen vaikutus energiahuoltoon*

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## Abstract

In this study the effect of climate change in Finland from 1961–1990 to 2021–2050 upon heating power demand of buildings, hydropower production, climatological potential of peat production, bioenergy, and wind energy was examined. Changes in monthly mean air temperature, precipitation and wind speed over the period 2021–2050, predicted by the global climate models, were used as input for hydrological models, and for heating power demand, wind power and peat harvesting calculations.

The climate projections were primarily taken from Hadley Centre's global climate model, HadCM3, simulations. The emission scenarios A2 and B2 of the Special Report on Emission Scenarios were used. The estimates of biomass changes were based on earlier studies.

The heating power demand will decrease by some 10% on average from the period 1961–1990 to 2021–2050. Hydropower production will increase by 7–11%, the climatological potential of peat production by 17–24%, the climatological potential of biomass (mainly wood) by 10–15% and the climatological potential of wind power by 2–10%. These results must be considered very preliminary.

## Tiivistelmä

Tutkimuksen tavoitteena oli selvittää ennakoidun ilmastonmuutoksen mahdollisia vaikutuksia rakennusten lämmitysenergiantarpeeseen, polttoturpeen korjuuedellytyksiin, bioenergiaan ja vesivoimaan sekä tuulienergian keskimääräiseen saatavuuteen Suomessa vuosina 2021–2050 jakson 1961–1990 keskimääräisiin ilmastollisiin oloihin verrattuna.

Tutkimuksessa käytettiin pääasiassa Hallitustenvälisen ilmastopaneelin uusimpia kasvihuonekaasujen ja aerosolien päästöskenaarioita A2 ja B2, ja niiden pohjalta englantilaisella Hadley-keskuksen ilmastomallilla HadCM3 tuotettuja projektioita ilmaston-muutoksesta (lämpötila, sadanta ja tuulen nopeus). Biomassan muutosarviot perustuivat aiempiin tutkimuksiin.

Tarkasteltu ilmastonmuutos lisää käytetystä skenaariosta riippuen jakson 2021–2050 keski-määräistä: bioenergian tuotantopotentiaalia eli lähinnä puupolttoaineen käyttömahdollisuuksia 10–15 %, polttoturpeen ilmastollista tuotantopotentiaalia 17–24 %, tuulivoiman ilmastopotentiaalia 2–10 % ja vesivoimatuotantoa 7–11 %, sekä vähentää rakennusten lämmitysenergian tarvetta noin 10 % jakson 1961–1990 keskimääräisoloihin verrattuna. Tutkimuksen tuloksia on pidettävä lähinnä suuntaa antavina.

# 1 Introduction

Our climate affects strongly the heating demand of buildings as well as the potential of power production, especially on power production based on renewable energy sources. Up to now quite few studies on the influence of climate change on power production in Finland are available.

The aim of the ILMAVA project (April to August 2002) was to produce basic information on the climate change effect upon the energy sector in Finland, from the period 1961–1990 to the period 2021–2050, by using newest information and model results on the climate change in northern Europe. The modelled changes are mainly due to estimated man-made changes in the composition of the atmosphere.

The project was implemented in co-operation with the Finnish Meteorological Institute and the Finnish Environment Institute as partners, and Fortum Oyj as a sub-contractor as part of the Climtech programme. The project was partially funded by Tekes[1] and Finergy[2].

### Objectives

The main objective was to study the effect of climate change on annual heating power demand and on energy production potential of hydropower, peat, biomass and wind power by the 2030s.

### Methodology

Changes in monthly mean air temperature, precipitation and wind speed over the period 2021–2050, predicted by the global climate models, were used as input for hydrological models, and for heating degree-day, peat harvesting and wind power calculations. For studies of biomass changes, the results from the earlier SILMU[3] programme were used.

# 2 Climate change

The span between the present and the 2030s is relatively short in respect to climate change. Within this time period the different modelled scenarios give projections where e.g. the rates of global warming are quite close to each other (Figure 1). A limited number of global climate model projections have been run for the IPCC[4] SRES[5] emission scenarios. Nearly all of them are for the illustrative A2 and B2 SRES emission scenarios that are not the most extreme ones but still cover a fairly large range of the possible emissions.

The climate change was studied by data taken from the different simulations:

a. Temperature, precipitation and wind predictions used in studies on power production were produced by the HadCM3 global climate model of the Hadley Centre in UK, using the SRES emission scenarios A2 and B2.
b. ECHAM4-GSD and HadCM3-AA simulations were used to study the changes in the degree-day statistics. Heating degree-days correlate very well with the heating power demand of buildings

As e.g. wind distribution strongly depends on the spatial resolution of the model, data from the higher resolution SMHI[6] regional climate model was also exploited.

The HadCM3 A2 and B2 simulations for this time span do not represent extreme projections as seen in Figure 2. Differences between the HadCM3 projections for seasonal change in precipitation probably depend more on natural variation of climate than the differences between the A2 and B2 emission scenarios.

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1 Tekes = The Finnish National Technology Agency; www.tekes.fi
2 Finergy = Finnish Energy Industries Federation; www.energia.fi/finergy/
3 SILMU = The Finnish research programme on climate change, 1990-1995
4 IPCC = Intergovernmental Panel on Climate Change
5 SRES = Special Report on Emission Scenarios
6 SMHI = Swedish Meteorological and Hydrological Institute

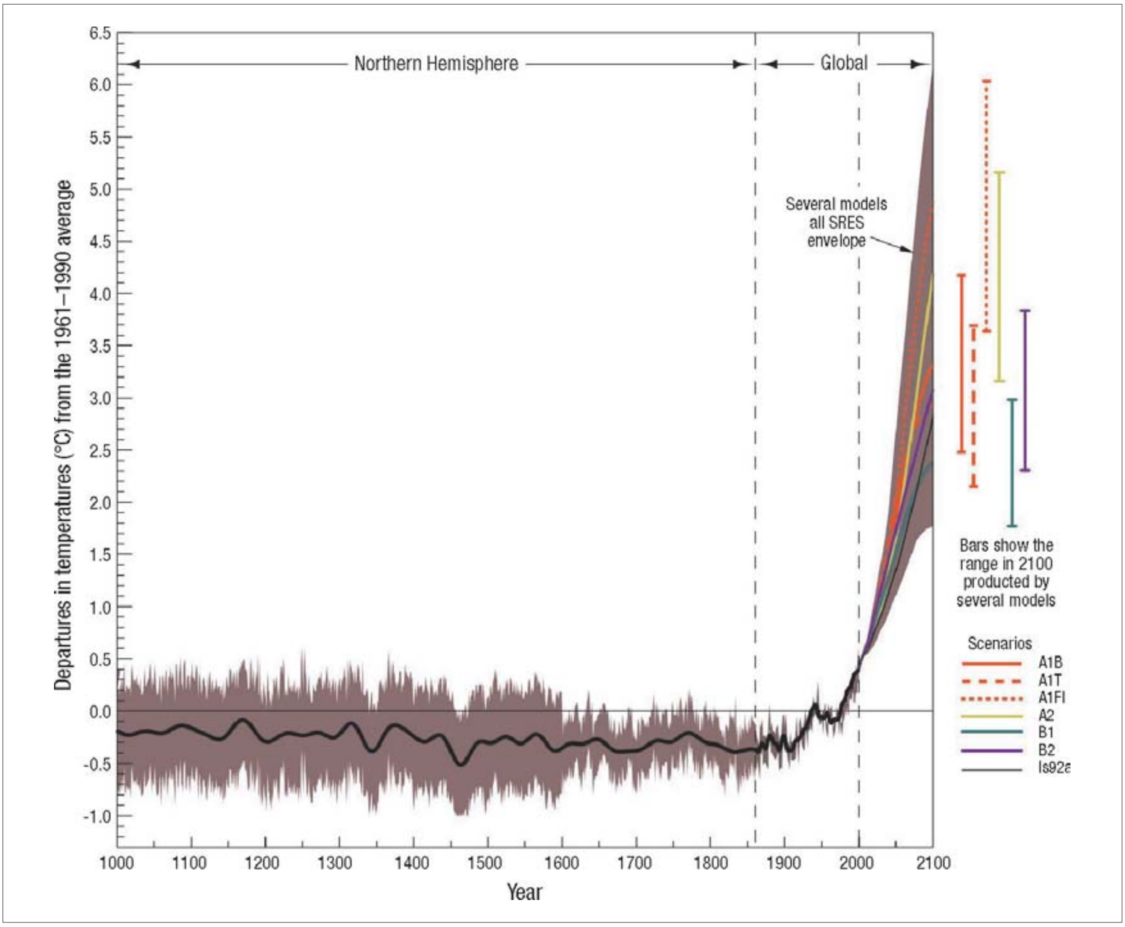


**Figure 1.** Variations of the Earth's surface temperature: years 1000 to 2100. From year 1000 to year 1860 variations in average surface temperature of the Northern Hemisphere are shown reconstructed from proxy data (tree rings, corals, ice cores and historical records. The line shows the 50-year average, the shaded region the 95% confidence limit in the annual data. From years 1860 to 2000 variations in observations of globally and annually averaged surface temperature from the instrumental record are shown. The line shows the decadal average. From year 2000 to 2100, projections of globally averaged surface temperatures are shown for the six illustrative SRES scenarios and IS92a using a model with average climate sensitivity. The shaded region marked "several models all SRES envelope" shows the range of results from the full range of the 35 SRES scenarios, in addition to those from a range of models with different climate sensitivities.

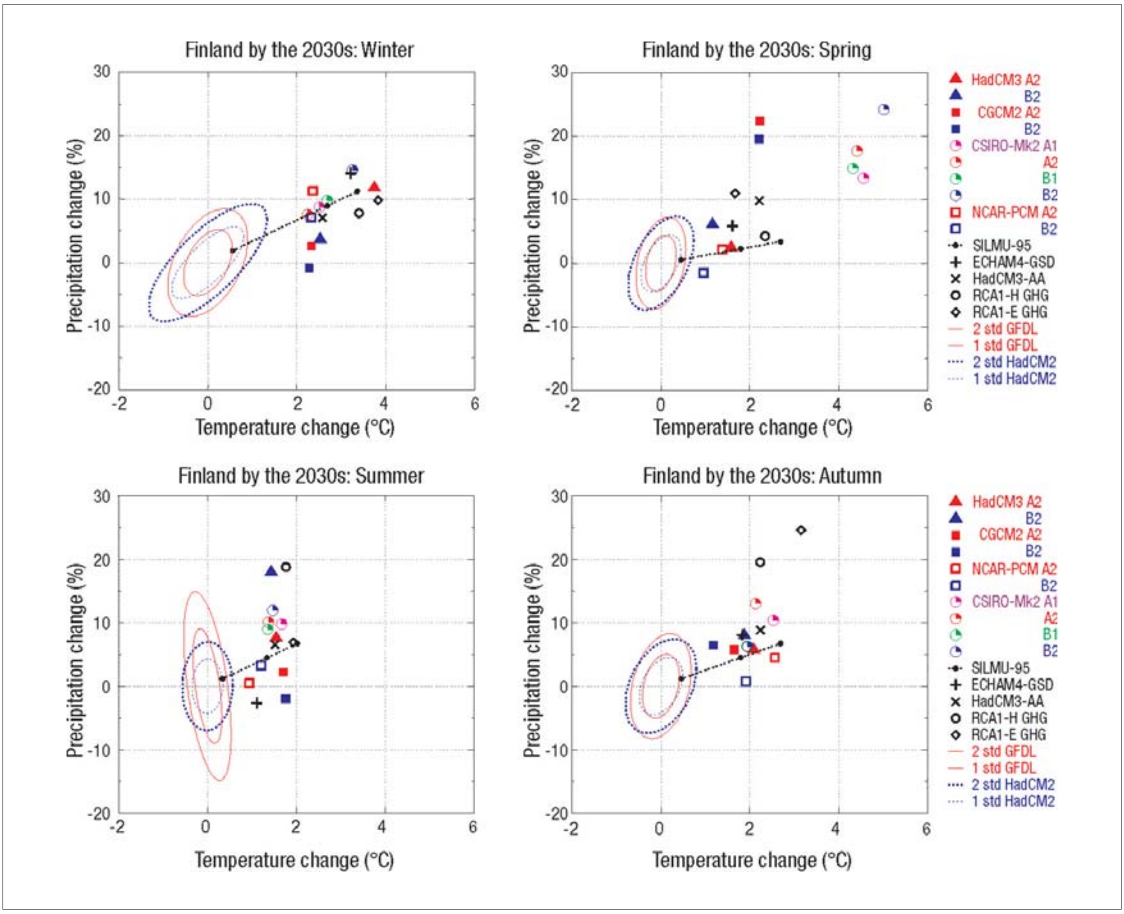


**Figure 2.** The seasonal change in temperature (horizontal axis) and precipitation (vertical axis) from the period 1961–1990 to 2021–2050 as predicted by global models and two regional models (RCA1-H and RCA-E). Coloured marks are for SRES-scenarios, and the black marks for results from earlier projections and SILMU scenarios. The natural variation of 30-year averages (±1 or ±2 standard deviation) is indicated by ellipses.

The parameters used as input for other models in the ILMAVA project were the change in surface air temperature, precipitation and wind speed at 10-meter height. In temperature the change is very uniform over Finland, A2 giving slightly bigger changes than B2. In precipitation and wind speed the changes are more unevenly distributed. There is larger uncertainty attached to the precipitation and wind projections than to the temperature projections.

As seen in Figure 3, the average annual increase in temperature over land in Finland is about 2°C, in annual precipitation 7–9 %, and for wind speed at 10 m height about 1%. However, for wind power production the potential sites are not at inland but offshore and in arctic fells. The sea areas are quite small in respect to the grid size of the global models so that the Baltic Sea conditions are not too well represented in the global models.

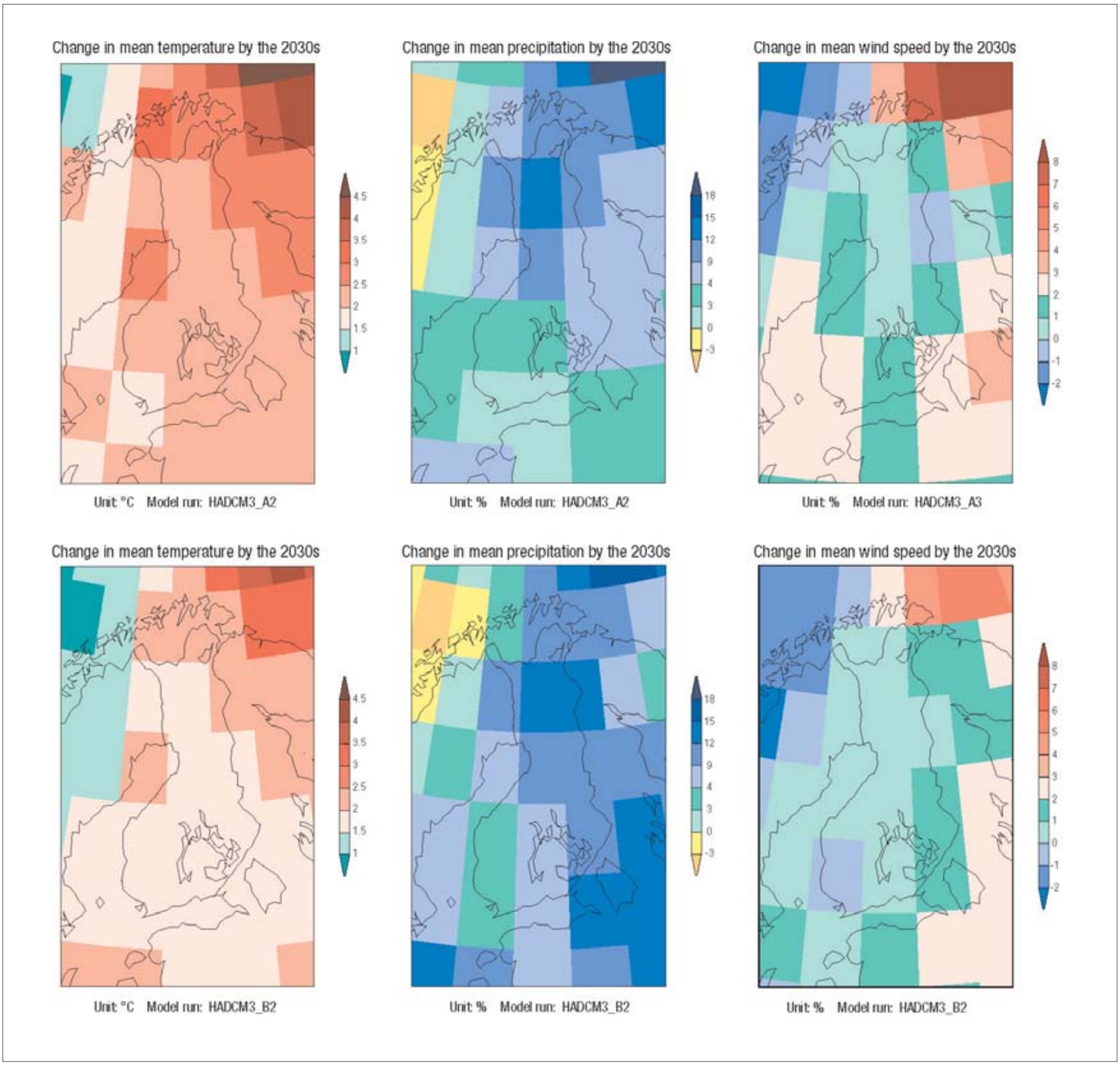


**Figure 3.** The climate change in the 2030s in Finland for air temperature (left, °C), precipitation (middle, %) and wind speed at 10 m (right, %) compared to the normal period 1961–1990 predicted by HadCM3 model using the scenarios A2 (top) and B2 (bottom).

The biggest uncertainties in predicting the climate in Finland in the 2030s are related to the limited ability of the global models to describe the regional distribution of the climate change, and the large natural variation of temperature, precipitation and wind.

# 3 Main results

## 3.1 Heating power demand of buildings

The projected wintertime warming lowers the heating power demand of buildings. However, the total heating power demand on buildings depends not only on the air temperature but also on many other parameters. The improved isolation and building techniques will probably decrease the power demand of buildings as well. The migration of the Finnish population from northern and eastern parts to southern Finland would decrease the total heating power demand, as southern Finland is warmer than the rest of the country.

On the other hand, the growth of population, decrease in the size of average households and ageing of the population will probably increase the heating power demand of average households. Also increased all-year-around usage of weekend houses, together with increased cooling of offices and public buildings, may increase the total power demand of buildings.

It is estimated that the power demand of buildings in Finland by the 2030s will decrease by some 10%.

## 3.2 Peat

According to climate projections used in ILMAVA, the precipitation sum during the peat producing season from May to August will increase on average by 11–20 mm. Simultaneously mean temperature will rise by about 1,7 °C. This will increase the climatological potential of milled peat production by 17–24%. The amount of energy produced using peat is at the moment roughly 18 terawatthours, and energy production is estimated to increase up to 26 terawatthours until 2010. Peat production is very dependent on weather, and if climatological peat production preconditions will improve as a result of climate change, it will also improve the reliability of production.

## 3.3 Biomass

In Finland, wood is an important source of energy, and today about 20% of primary energy production and about 10% of electricity is obtained using wood fuel. According to the scenarios used by the SILMU project, the annual growth of forests will in Finland increase about 20% and logging about 15%. According to the bioenergy program, the potential to increase use of wood fuel until the year 2035 is 11–55 terawatthours. The anticipated increase of biomass will increase this potential by the amount of increase of logging potential, i.e., about 15%.

## 3.4 Hydropower

To estimate the changes in hydropower production, hydrological modelling was done for three representative watersheds: Vuoksi, Oulujoki and Kemijoki. The change in hydropower production in other watersheds was estimated using these three watersheds as references.

The aim was to assess how much climate change will affect the production of hydroelectric power in Finland. The effects of climate change on water resources have been evaluated using conceptual watershed models. Two scenarios of HadCM3 climate model are used as climate change approximations. The evaluated terms are runoff, evapo-transpiration, lake evaporation, water equivalent of snow, soil moisture, groundwater storage, discharge and water level. The precipitation and temperature changes will affect the annual water balance, especially on the seasonal distribution of water balance terms. Water equivalent of snow will decrease about 50 percent and the duration of the snow cover period will be shortened by two months due to warming. In general, summers will be dryer due to shorter snow cover season, increased evapo-transpiration from soil and increased evaporation from lakes, whereas winters will be wetter due to frequent snow melt periods and increased precipitation. The annual runoff will increase 0–8% depending on the location of the watershed and on the climate change scenario used. The runoff increase is largest in northern Finland (Table 1) and in winter (Table 2).

**Table 1.** Estimated change in hydropower production in different watersheds.

| Water system | 1061–1990 GWh/a | HadCM3 A2 | | HadCM3 B2 | |
|---|---|---|---|---|---|
| | | Change % | GWh/a | Change % | GWh/a |
| Oulujoki | 2600 | +2,8 | 2673 | +7,4 | 2792 |
| Kemijoki | 4440 | +15,2 | 5117 | +17,2 | 5202 |
| Vuoksi | 2100 | –0,1 | 2098 | +7,6 | 2260 |
| Iijoki | 850 | +10,3 | 938 | +11,8 | 950 |
| Kokemäenjoki | 1030 | –0,1 | 1029 | +7,6 | 1108 |
| Kymijoki | 1300 | –0,1 | 1299 | +7,6 | 1399 |
| Others | 400 | +3,2 | 413 | +8,8 | 435 |
| **Total** | **12 720** | **+6,6** | **13 565** | **+11,2** | **14 148** |

**Table 2.** Seasonal variation of average hydropower potential (MW) in Finland.

| | 1961–90t | HadCM3 A2 | | HadCM3 B2 | |
|---|---|---|---|---|---|
| December - February | 1434 | 1816 | +26% | 1795 | +25% |
| March - May | 1432 | 1592 | +7% | 1673 | +17% |
| June - August | 1516 | 1332 | –12% | 1480 | –2% |
| September -November | 1428 | 1452 | +2% | 1518 | +6% |
| **Mean** | **1452** | **1548** | **+7%** | **1616** | **+11%** |

According to the HadCM3 A2 and B2 projections, the average power produced by hydropower plants will increase by 7% and 11%, respectively. The change in power production figures differs significantly between the water systems, as seen in Table 1. These estimates include e.g. the uncertainties caused by the limited capability of global models to describe regional precipitation and the quite simple calculation of evaporation in the hydrological models.

### 3.5 Wind power

The rate of wind power production depends mainly on the size and the characteristics of the wind turbine, on air temperature and wind speed at the hub height, and on rime accretion on the blades and control sensors. In Finland, high production of wind power occurs during the winter months, while in summer the average wind speed is significantly smaller.

The potential locations for wind power production are offshore, in the archipelago, on the coast and at the fells.

The change in wind power potential, taking into account only the changes in regional average wind speeds at the height of 80 m, was studied. The Weibull distribution of wind speed was used to calculate the power output from a typical wind turbine. As the cut-off speed for the turbine was taken to be 25 m/s, the calculations do not take into account the changes in the extreme wind speeds.

According to the HadCM3 A2 projection, the wind power potential would increase at representative regions by 4–10%, giving an average number of about +7%. Using the B2 scenario, growth in power production only occurs in the area of Åland archipelago (+5%) and south-eastern part of Finland close to the Gulf of Finland (+8%).

As the wind speed close to earth surface highly depends on the roughness of the surface, wind speed is a very local parameter. According to results from the SMHI regional climate model, the largest changes in wind speed will occur at the sea areas in winter, providing an increase in offshore wind potential by some 20–30% in winter and 10–15% annually.

## 4 Concluding remarks

The used scenarios and projections indicate significant changes in the climate during the forthcoming 50 years. These climatic changes will very likely affect renewable energy resources and heating energy demand in Finland.

In general, the two scenarios A2 and B2 produce somewhat different projections for the future: A2 gives larger changes in temperature (bigger warming, more decrease in heating power demand) and in surface wind speed (increased wind power) than B2. To the contrary, B2 increases precipitation and hydropower production more than A2.

The given results include several uncertainties, which are partly taken into account as shown in Figure 4.

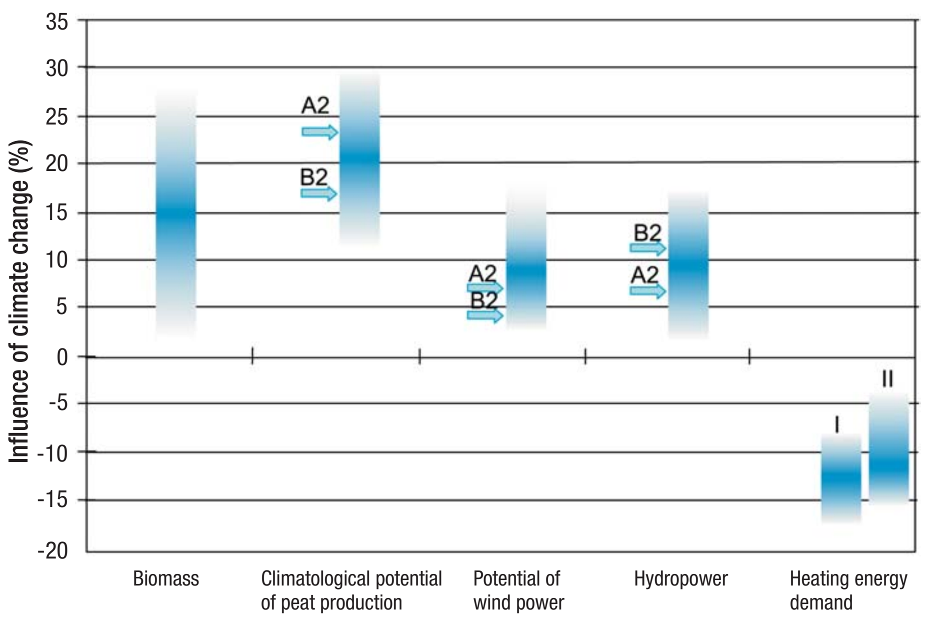


**Figure 4.** The influence of projected climate change on energy production potential and heating energy demand. Arrows depict relative changes between 1961–1990 and 2021–2050 based on scenarios HadCM3 A2 and B2. The change in biomass is based on SILMU scenarios. Also in the case of heating energy demand the calculations are based on different model simulations and scenarios and thus arrows depicting A2 and B2 scenarios have been excluded. In the case of heating energy demand the bar I represents the situation where only the influence of climate change has been taken into account. The bar II represents the situation where beside climate change also the influence e.g. of the migration of population, development of housing of other factors have been estimated.

The effect of the climate change on the energy sector and electric power production depends on the rate of the change of temperature, precipitation, humidity, evaporation and wind, but also on the structure of power production. As the span from the present to the 2030s is after all quite short, it is assumed that the structure of energy supply in the 2030s will be much like the present one. Thus in this project only the effect of climate change upon weather parameters were taken into account.

These results are very preliminary. It is obvious that more reliable, detailed data on regional variation of weather parameters produced by improved regional models are required for more advanced projections on the effect of climate change on energy resources in Finland. As we will live in an open electricity market, it is necessary to study the changes in an area covering at least the whole region of the Nordic countries and perhaps even the area around of the Baltic Sea.

### Publications and reports made under the project

Tammelin, B., Forsius, J., Jylhä, K., Järvinen, P., Koskela, J., Tuomenvirta, H., Turunen, M., Vehviläinen, B., Venäläinen, A. Ilmastonmuutoksen vaikutus energiahuoltoon. [*The Impact of Climate Change on Energy Management. (In Finnish).*]. Finnish Meteorological Institute, 2002. (to be published).

## Local Means of Livelihood in Mitigating Climate Change – The Case of Southeast Finland

*Paikalliset elinkeinot ilmastonmuutoksen torjunnassa Kaakkois-Suomessa*

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### Abstract

A reduction of greenhouse gases (GHG) will be necessary in order to control the climatic change in the near future. This is a fact that should be understood by companies and corporations as a possibility, which could lead to measures that would allow the development of regional business and industry.

The objective of this research was to find the most effective methods and operational models for developing the industry in southeastern Finland in order to reduce greenhouse gas emissions. In particular, this report discusses the opportunities, related to municipal activities, to influence attainment of the objectives. This work was implemented as a part of the climate protection campaign, co-ordinated by the Association of Finnish Local and Regional Authorities, and is a preliminary research carried out on the basis of literature as well as, in the case of the examples cited, information obtained from interviews of local companies.

In order to develop business that will reduce GHG emissions, this report studied methods for improving the competitiveness of existing companies and for developing new business. Company networking was seen as being a crucial way in achieving these goals and improving the opportunities for the region's many small companies to deliver large projects and comprehensive orders. This report presents an operational model for company networking, which is suited for municipal activity. As for various kinds of waste and by-products, this report puts forward a business model for the control of the material flows in the form of a so-called material trading market.

### Tiivistelmä

Kasvihuonekaasujen vähentäminen on lähitulevaisuudessa välttämätöntä ilmastonmuutoksen torjunnassa. Tämä tosiasia tulisi nähdä niin yrityksissä kuin kunnissakin mahdollisuutena, johon liittyvillä toimenpiteillä voitaisiin kehittää myös alueen liiketoimintaa ja elinkeinoelämää.

Tutkimuksen tavoitteena oli löytää Kaakkois-Suomen kannalta tehokkaimmat keinot ja toimintamallit alueen liiketoiminnan edistämiseksi kasvihuonekaasupäästöjä hillitsevään suuntaan. Työssä on käsitelty erityisesti kunnan toimintaan liittyviä vaikutusmahdollisuuksia tavoitteiden saavuttamisessa. Tutkimus on toteutettu osana Suomen Kuntaliitto Ry:n koordinoimaa kuntien ilmastonsuojelukampanjaa. Tutkimus on luonteeltaan kirjallisuuden pohjalta tehty esiselvitys. Työhön sisältyvien esimerkkitapausten osalta on tietoa hankittu myös haastattelemalla alueen yrityksiä.

Kasvihuonekaasuja vähentävän liiketoiminnan edistämiseksi on selvitetty keinoja sekä olemassa olevien yritysten kilpailukyvyn parantamiseen että uuden liiketoiminnan kehittämiseen liittyen. Näiden tavoitteiden saavuttamisessa nähtiin yritysten verkostoitumisen olevan eräs tärkeä keino, jolla voidaan parantaa muun muassa alueen lukuisten pienten yritysten mahdollisuuksia suurten kokonaistoimitusten tuottamisessa. Raportissa on esitetty kunnan toimintaan soveltuva toimintamalli yritysten verkostoimiseksi sekä jätteiden ja sivutuotteiden osalta on esitetty materiaalivirtojen hyötykäyttöön ohjaamiseen erikoistunutta liiketoimintaa niin sanotun materiaalipörssin muodossa.

# 1 Introduction

In December1997, the Kyoto Conference of the parties to the UNFCCC agreed to the Kyoto Protocol that set quantitative limits to the emissions of greenhouse gases for a number of industrialized countries. Finland is required to maintain approximately the 1990 emissions level during the first Commitment Period form 2008 to 2012.

The Finnish Government adopted the National Climate Strategy on March 15, 2001, and the Strategy was supported by the Parliament in its statement on June 19, 2001. The Strategy contains only domestic actions of GHG reduction to attain the objective of the Kyoto Protocol. Concerning this research in the National Climate Strategy it is mentioned that local communities have a significant role in emitting GHG, and also in affecting other emissions. This also means responsibility to implement actions for reducing emissions. Local communities have their opportunities to operate in regional areas. In order to reduce greenhouse gases, possibilities have to be observed locally. Every region has its special characteristics, which form typical potentials and limitations of a region to control emissions.

Many actions can easily be changed using present technologies to attain equal or even better results with minimum emissions. Anyhow, that requires being aware of the present situation and also of those possibilities that are available. When required information about resources and methods is available, strategic decisions and operation models can be used to achieve a new way of operation.

The principal aim of this research is not maximal reduction of GHG emission but rather finding commercial opportunities to increase local interests. Other objectives of the research were to find the most effective operation models for Southeast Finland in order to improve the local economy, to raise employment and at the same time to control GHG emissions.

# 2 The essential content of study

In order to develop business that will reduce GHG emissions, this study proposes methods for improving the competitiveness of existing companies and for developing new business.

## 2.1 The possibilities and potentials to reduce greenhouse gas emissions in Southeast Finland

The beginning of this research examines the special characteristics and potentials of Southeast Finland. The reductions in greenhouse gas emissions and the effects on employment, which could be achieved by tapping the potential for the increase in the use of renewable energy sources in Southeast Finland, are estimated (see Table 1). On the basis

**Table 1.** The potential of additional renewable energy production and the corresponding greenhouse gas emission reduction and employment effect in Southeast Finland.

| | **Potential [MW] [TWh/a]** | **$CO_2$ eq. reduction potential [$tco_2$/a]** | **Employment effect under construction [person/a]** | **Employment effect as working time [person/a]** |
|---|---|---|---|---|
| Wind power | 13 MW, 0.0325 TWh/a | 9750–22750 | 52 | 3.25–6.5 |
| Small scale water power | 12 MW, 0.048 TWh/a | 11900–40800 | 180 | 0 |
| Photovoltaic | 0.060 TWh/a | 10500–40000 | 100–200 | 0 |
| Solar thermal energy | 0.1 TWh/a | 30000–45500 | 200–300 | 0 |
| Heat pump | 0.48 TWh/a | 88 000 | – | 0 |

created by these potentials, the possibilities for developing business that would be suited to the region's industrial structure are analyzed.

### 2.2 Means to improve competitiveness and to develop new business

One possibility for the local communities is to develop an operational model (see Figure 1), the purpose of which is to advance business that will reduce greenhouse gas emissions in the companies of the region. A trade ombudsman or a communal business developing company of local communities could help to establish business relations between progressive companies working with the environmental sector and other companies like subcontractors, public authorities or financiers. With this operational model, local communities can advance for instance networking and competitiveness of companies on their own region.

### 2.3 The activity supporting the growth of the local business

The most significant issues that affect promotion of business growth reducing GHG emissions are education, research and financing. These issues are studied to find out, which kinds of activity exist in Southeast Finland related to the subject of this report.

In the region of Southeast Finland there is only one university, the Lappeenranta University of Technology (LTKK). Related to the subject of this report, LTKK has both education and research in the following departments: Department of energy and environmental technology, Department of industrial engineering and management, and Department of business administration. Education and research has been focused especially in view of the requirements of companies. In Southeast Finland there are also two Polytechnics, whose practical

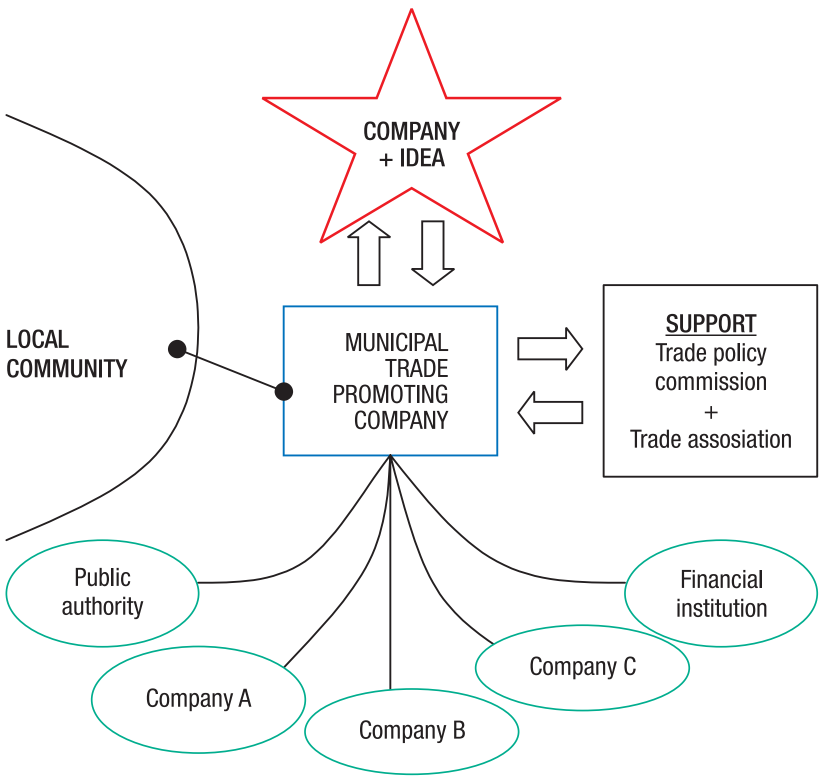


**Figure 1.** An operational model for company networking which is suited for municipal activity.

close knowledge gives facility and basic information about methods to reduce GHG emissions. Each of these educational systems offers also further and supplementary education.

Financing is one of the supporting elements of business. A direct link between financing and climatic change is possible. For example ESCO (Energy Service Company) finances only energy saving investments. Energy saving is one of the most effective methods to reduce GHG emissions. In addition, ESCO itself is one form of business that finances and erects energy saving turnkey equipment for customers. The customer repays the costs for equipment to ESCO in incomings gained from energy savings. The local communities have plenty of potential targets to save energy by using ESCO.

## 2.4 Case studies

Case studies play an essential role in this research, because they form the framework within which local companies and authorities were interviewed. The subjects of the cases are the factors and methods related to the material trading market and heating entrepreneurship. Based on the information obtained from the interviews and literature, new models of operation for developing current business practices were proposed.

### 2.4.1 The material trading market

The material trading market is a company, which transmits waste materials and byproducts from material producers to appropriate employers, and gives advice related to re-use and recycling. Up to the present time, existing material trading market systems have been exchange services of information between material producers and customers and vice versa. Existing markets have operated mainly on internet. In the case study it was examined how the material trading market could be developed so that major part of the materials would be effectively redirected to re-use and recycling. Using materials effectively affects positively to the climatic change, because using recycled materials in production consumes less energy. The methane emissions are also lower, due to decreasing amount of biodegradable waste on landfills. Running a material trading market may become a form of business as soon as customers can be charged for services.

To develop an idea of the material trading market, four representatives of companies and one authority of a city were interviewed. Commonly it seemed that the material trading market could have two alternative operational models related to transmission of materials. In the first alternative the material trading market only transmits materials and takes a fee from the producer of material and in the second possibility the material trading market byes materials and sells them forward.

The material trading market could include different kinds of services like finding out potential further processing and utilization for materials, regional transportation, organized reception of materials in different regions, treatment of materials, guidance and information and management of authority affairs.

Local communities can advance operation of the material trading market to redirect their own kinds of waste and by-products to re-use or recycling using the services of the material trading market. This kind of activity has positive influence in employment, and GHG emissions can also be reduced by using materials more effectively.

### 2.4.2 The heating entrepreneurship

The heating entrepreneurship is a form of local small-scale business, which produces heat to the use of local community's estate or heating station by using indigenous fuels.

The first heating entrepreneurs started in the beginning of 1990's. Since then the number of boiler plants heated by an entrepreneur have been squarely increased (Figure 2). At the beginning of 2002, the number of heating entrepreneurs was a bit more than 130. Only two of these are located in Southeast Finland.

As one form of energy production, heating entrepreneurship is a lucrative alternative to produce thermal energy because of its benefits for local communities. Heating entrepreneurship employs

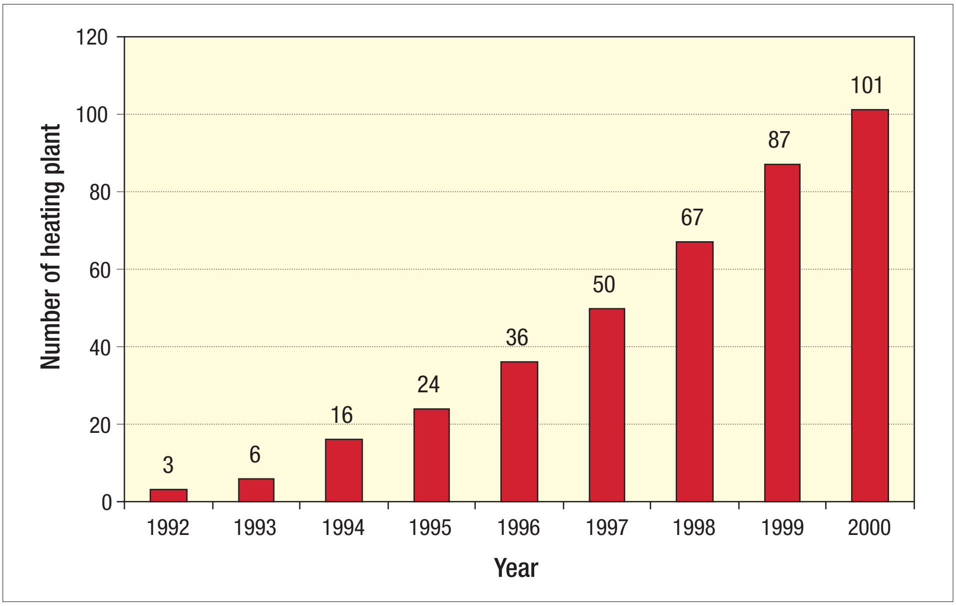


**Figure 2.** Increase in the heating entrepreneurship during 1992–2000.

persons regionally more than ten-fold compared with usage of foreign fuels, and the money used for heating mainly stays in the same area. Boilers heated by indigenous fuels like wood chips do not cause GHG-emissions.

At present there do not exist any operational models for augmentation of the heating entrepreneurship. Problems in augmentation of the heating entrepreneurship are for example: finding appropriate heating object, lack of fuel suppliers of fuels and equipment and finding investors. Local authorities could help to solve these problems for example by finding an appropriate heating object, arranging education for entrepreneurs and producing information. Some kind of forum would be also useful for changing information between heating entrepreneurs.

## 3 Discussion

One objective of the research was to find regionally suitable methods and operation models to develop business that will reduce GHG emissions. Results of the research are particularly accentuated to the field of energy production, energy saving and waste treatment. Among these fields, potentials of activities, employing effect and GHG reduction has been examined. In studying of potentials, problems have been faced because of the incoherence of information. Pieces of information collected from different sources are not comparable with each other. Thus, it was not possible to prove the superiority of alternative methods reliably. Concrete methods suitable for the use in practise are presented in case studies.

## 4 Conclusions

According to this study, some of the most important means to develop business and to reduce GHG emissions are the development of operational models for local authorities, material trading market and methods to utilize indigenous fuels like heating entrepreneurship. In particular, development of operation model of communal business developing company was found important, because with its use it is possible to affect all the methods and operation models found in the research. Networking of companies and cooperation between companies and the public sector can also activate the means referred to above.

## 4.1 Further activities

The preliminary research was carried out mainly on the basis of literature. Based on the results of this study, the intention is to start a pilot project. The purpose of the pilot project is to develop further significant methods found in the preliminary research, especially related to local business that will reduce GHG emissions. The following list gives proposals for objectives of the pilot project.

The purpose of pilot project is:

- To start the heating entrepreneurship, to match the heat demand of the local heating needs and the heat suppliers' (existing and new heating entrepreneurs) possibility to produce heat.
- To find adaptable ways of action for local communities to re-use and recycle various kinds of waste through a material trading market.
- To develop, in cooperation with local communities, an operational model for a municipal business developing company or trade ombudsman to increase business that will reduce GHG emissions.
- To start energy, emission and waste inspections together with small local communities.
- To start purchasing of energy saving and emission lowering equipment in cooperation between small communities.

### Publications and reports made under the project

Lappalainen, S. 2002. Paikalliset elinkeinot ja ilmastonmuutos Kaakkois-Suomen alueella. [*Local industries and climatic change in Southeast Finland. (In Finnish, with English abstract)*]. Lappeenranta University of Technology, Lappeenranta. Master's thesis. 121 p. + app. 2 p.

# The Impacts of Climate Change Mitigation on Air Pollutant Emissions

*Kasvihuonekaasujen päästöjen vähentämisen vaikutus muihin ilmansaasteisiin*

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## Abstract

This paper presents the results of an assessment examining the side effects of greenhouse control measures on the emissions of other harmful air pollutants (so-called ancillary benefits) done in the context of the Climtech technology programme. The viewpoints considered were Finnish, European and global. The global assessment was based on existing literature and recent scientific findings reported. The national scale study was done with the help of energy system modelling. The EFOM-ENV model available at VTT was expanded by adding modules for the calculation of fine particle emissions. In addition, the existing routines and databases for the calculation of sulphur and nitrogen oxides in the EFOM model were updated to correspond to the latest status of reduction technologies and recent amendments in emission control legislation. Scenario studies extending to the year 2030, assuming various levels of greenhouse gas emission reductions, were performed with the EFOM model. The EFOM model was used to find the cost-optimal ways for achieving the specified greenhouse gas emission reductions, and the model calculated the simultaneous changes occurring in the emissions of other air pollutants. The model studies for the Finnish energy system indicated that significant ancillary benefits in air pollution reduction can be achieved. A -20% greenhouse gas cutback requirement by the year 2030 from the 1990 level yielded a simultaneous reduction of 11–16% in sulphur emissions and a 8–9% reduction in $NO_x$ emissions, compared to a greenhouse gas emission stabilisation at the 1990 level. Technical reduction measures of particulate emissions, especially from small-scale combustion, determine the future development of total national particulate emissions far more than structural changes in large-scale energy production, which already executes effective emission control. The greatest uncertainties in the results lie in the average present level and the possible future changes of fine particle emissions from small- scale combustion. The results obtained for Finland are in accordance with corresponding studies from other regions indicating significant ancillary benefits in reduced air pollution. As the general recognition of the health hazards of air pollution is growing, this may actually promote significantly the export opportunities of advanced Finnish technological knowledge and energy technologies, offering solutions also for, *e.g.*, local air pollution. Especially in developing countries, the significant improvements in local environmental conditions achieved with cleaner technology may actually be more decisive implementation factors than GHG reductions.

## Tiivistelmä

Tämän hankkeen tavoitteena oli selvittää lyhyen ja keskipitkän aikavälin (vuoteen 2030) keskeisimpien GHG-vähennystoimien merkittävät suorat sivuvaikutukset muiden haitallisten aineiden ilmapäästöihin ja niiden aiheuttamiin ympäristöongelmiin. Näkökulmina olivat suomalainen ja Euroopan laajuinen, sekä soveltuvilta osin globaali. Työn Suomea koskevassa osassa käytettiin VTT:n EFOM-ENV-energiajärjestelmämallia arvioimaan, mitä muutoksia ilmansaasteiden päästöissä on odotettavissa kasvihuonekaasujen vähentämistoimenpiteiden myötä. Työn globaali osuus perustui kirjallisuuteen ja uusimpiin raportoituihin tieteellisiin havaintoihin aiheesta. Työssä laajennettiin EFOM-mallia kattamaan myös pienhiukkasten päästöjen laskenta. Lisäksi työssä päivitettiin jo olemassa olevat rikin ja typen oksidien laskentaa koskevat laskentarutiinit ja tietokannat vastaamaan uusinta tietämystä rajoitustekniikoiden ominaisuuksista. Samoin huomioitiin uusimmat lisäykset ja muutokset ilmansaasteiden päästöjä koskevassa lain-

säädännössä. EFOM-mallilla tarkasteltiin vuoteen 2030 ulottuvia skenaarioita. Mallilla laskettiin tilanteita, joissa Suomen kasvihuonekaasujen päästöjä rajoitettiin mahdollisimman kokonaisedullisella tavalla. Malli laski samalla tapahtuvat muutokset muiden ilmansaasteiden päästöissä. Tarkastelut osoittivat, että kasvihuonekaasujen päästöjen rajoittamistoimenpiteillä voidaan saavuttaa myös merkittäviä sivuhyötyjä muiden ilmansaasteiden päästöjen vähentämisessä. Kasvihuonekaasujen -20% rajoitustavoiteskenaariossa vuoteen 2030 asti rikkipäästöjen rakenteellinen vähenemä oli 11–16% ja typenoksidien rakenteellinen vähenemä 8–9% verrattuna tilanteeseen, jossa Suomi toteuttaa vain Kioton pöytäkirjan. Pienhiukkasten kokonaispäästöjen kehityksessä tekniset rajoitustoimet erityisesti pienlähteissä ovat oleellisempia kuin rakenteelliset muutokset suuren mittakaavan energiantuotannossa. Suurimmat tulosten epävarmuudet ovat pienhiukkasten osalta pienlähteiden päästöjen keskimääräisessä nykytasossa ja tulevaisuuden kehityksessä. Tulokset olivat yhdenmukaisia kansainvälisten tutkimusten kanssa. Lisääntyvä tietoisuus ilmansaasteiden aiheuttamista terveysriskeistä voi osoittautua lähitulevaisuudessa hyvin merkittäväksi tekijäksi lisäämään puhtaampien teknologioiden globaalia kysyntää ja siten vauhdittamaan myös suomalaista teknologiavientiä.

## 1 Introduction

The reduction of greenhouse gases (GHGs) causing warming of earth's climate is among the greatest challenges that the global energy system is presently facing. The stabilisation of atmospheric carbon dioxide concentrations at levels corresponding to a doubling or less of the pre-industrial level requires emission reductions of 50–80% from the present during this Century (IPCC 2001). This would imply dramatic changes in the global energy infrastructures.

Already now, with the first reduction steps envisaged to be taken with the Kyoto protocol, questions about the side effects of the greenhouse gas emission reduction measures have risen. At broadest, it is a question of how the mitigation of climate change interacts with the objective of global sustainable development. The side effects of climate change mitigation range across a wide variety of sectors, such as transportation, agriculture, waste management or land-use practices. The side effects can be either positive or negative. This emphasizes the need for research and careful design of the planned measures in order to avoid negative side-impacts.

The Third Assessment Report of the IPCC (IPCC 2001) reviewed the status of knowledge about the side-impacts of climate change mitigation. In brief, it concluded that significant ancillary benefits are possible, especially in the reduction of local and regional air pollution, but that large gaps in knowledge still exist. For future research, the IPCC recommended further development of analytical tools for evaluating the ancillary benefits of climate change mitigation and further assessment of the side-impacts of climate mitigation options.

The purpose of this study was to examine the side effects of greenhouse control measures on the emissions of other harmful air pollutants (so-called ancillary benefits), especially for the Finnish situation under various medium-term reduction requirements (from the present until 2030). In the scenario studies for Finland, the EFOM model available at VTT was used to find the cost-optimal ways for achieving the specified greenhouse gas emission reductions, and the model calculated the simultaneous changes occurring in the emissions of other air pollutants. European and global aspects were studied mainly by literature review. The study concentrated on the emissions of fine particles, sulphur and nitrogen oxides.

## 2 Methods

This study utilised the EFOM-ENV energy system model for Finland available at VTT. The EFOM-ENV is a linear optimizing energy system model used at VTT Processes (Lehtilä and Pirilä 1996, Lehtilä and Tuhkanen 1999). The EFOM model calculates energy supply and demand with user-defined pre-conditions and constraints, such as fuel prices or total GHG emission ceilings. The model determines for any study period the cost-optimal mix of fuels and technologies with the given boundary conditions.

In this work, the EFOM model was expanded by adding modules for the calculation of fine particle emissions. In addition, the existing routines and databases for the calculation of sulphur and nitrogen oxides in the EFOM model were updated to correspond to the latest status of reduction technologies and recent amendments in emission control legislation. Scenario studies extending to the year 2030, assuming various levels of greenhouse gas emission reductions, were performed with the EFOM model. EFOM was used to find the cost-optimal ways for achieving the specified greenhouse gas emission reductions, and the model calculated the simultaneous changes occurring in the emissions of other air pollutants. Figure 1 presents the modelling principle. The dashed boxes indicate the model additions done in this work.

### 2.1 Recent legislation concerning air pollutant emissions

The EU has recently published several significant new directives regulating air pollutant emissions. The National Emission Ceilings (NEC) directive (EU 2001a) sets country-specific ceilings for total annual emissions of sulphur, nitrogen oxides, ammonia and volatile organic compounds (VOCs) to be achieved by the year 2010. In parallel with the NEC directive, the EU revised the Large Combustion Plants (LCP) directive, which regulates the emissions from all combustion plants greater than 50 $MW_{th}$ (EU 2001b). The NEC directive is together with the revision of the LCP directive the main instrument towards achieving the Union's long-term air quality objectives, *i.e.*, the elimination of excess acid deposition and reduction of tro-

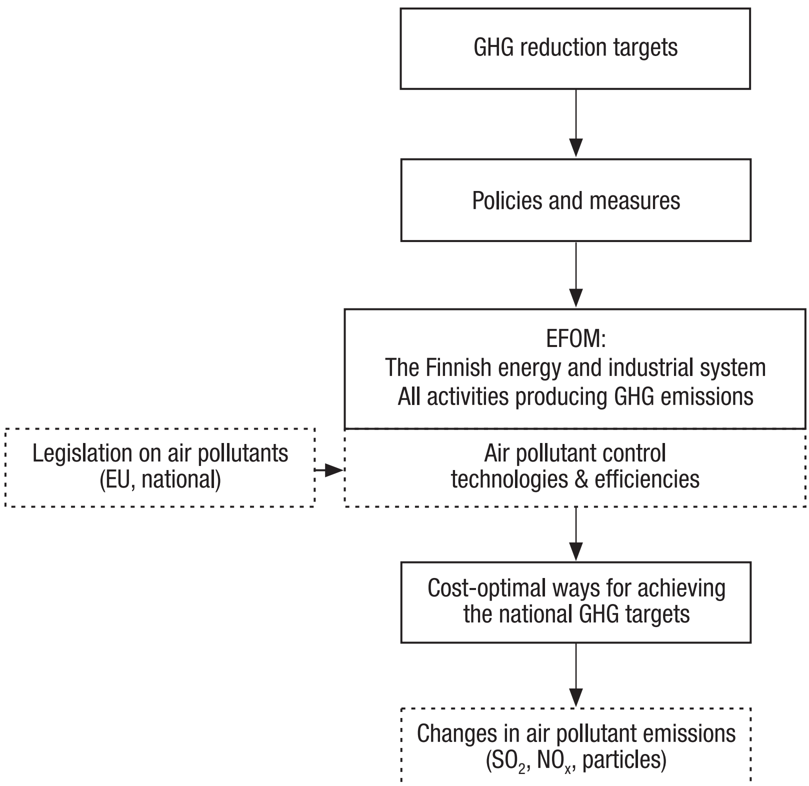


**Figure 1.** The modelling framework used in the study. The dashed boxes indicate the additions done in this work.

pospheric (=ground-level) ozone below levels harmful for human health and vegetation (EU 2001a). In addition to the NEC and LCP directives, the EU has completed the work on the regulation of emissions from waste incineration. All these directives are to be implemented in the national legislation of the EU member countries within one year of their publication. In Finland, the national programme on implementation is underway at the moment of writing.

Emissions from the transport sector have been regulated in the context of the Auto-Oil programmes in the EU. The emission specifications for new cars, heavy-duty vehicles, off-road vehicles, etc. are progressively tightened (European Commission 2000). Altogether, these directives imply very significant reductions in harmful air pollutant emissions (excluding greenhouse gases) from the transport sector in the future.

The new CAFÉ (Clean Air For Europe) programme of the EU has set special emphasis on pollution causing adverse effects on public health, *i.e.*, fine particle concentrations and high tropospheric ozone levels. Within the CAFÉ programme, new directive proposals targeting the emissions of particles and ozone precursors ($NO_x$ and VOCs) are envisaged for the year 2005.

The Framework Convention on Long-Range Transboundary Air Pollution of the United Nations Economic Commission on Europe (UN/ECE) covers practically all countries in Europe, including the areas of the former Soviet Union. The so-called Göteborg protocol, signed in 1999, has set emission ceilings for acidifying, eutrophying and ozone-forming air pollutants (UN/ECE 1999). For the EU countries, the emission ceilings of the Göteborg protocol are somewhat higher than those set in the NEC directive.

### 2.2 Implementation of air pollutant emission coefficients into the EFOM model

Based on air pollution control legislation and on technology-specific typical emission reduction levels of control techniques at use, average emission coefficients for all relevant fuels and technologies in the Finnish energy and industrial system were implemented into the EFOM model. The database of the EFOM model contains some 150 energy production and conversion technologies and size classifications. The technology and size classes cover all technologies presently at use, as well as foreseeable future technologies, such as supercritical coal power plants, gas conversion technologies, fuel cell technologies, etc.

Fine particle emission calculation routines were developed for total suspended particles (TSP) and for the PM2,5 size fraction. Particulate emission coefficients were specified separately for small-scale combustion and for large facilities in the EFOM model. Small-scale combustion was modelled by including the most relevant source types (stoves, fireplaces, heating boilers, etc.) and by distinguishing between old-type and modern-type installations. Fine particle emission coeffients used are based on (Ohlström 1998, Jokiniemi 2002, Karvosenoja 2001, Lûkewille et al. 2001, Nussbaumer 2001).

For industrial processes, emission coefficients were based mainly on companies' published environmental information and on environmental statistics (*e.g.*, Rautaruukki Ltd. 2001, Outokumpu Ltd. 2001, Fortum Ltd. 2002, Statistics Finland 2001).

For the transport sector, emission coefficients applied are based on the LIPASTO model of the VTT (Mäkelä 2002) and on the relevant EU Auto-Oil directives specifying the allowed and expected emission levels of present and future engine and fuel types (European Commission 2000).

## 3 Scenarios studied

The EFOM model scenarios were specified by the Climtech technology programme. The scenario studies extended to the year 2030. The possible future developments were assessed for two alternative scenarios:

- 'Conventional' development: International climate change mitigation measures evolve rather slowly. There are no significant changes in the

support for the development and commercialisation of cleaner technologies. As a result, new technologies reducing greenhouse gas emissions penetrate rather slowly into the energy and industrial systems.
- 'Optimistic' development: As a result of accelerating climate change mitigation measures both internationally and within Finland, cleaner technologies develop rapidly and they are taken into use effectively. This assumes also increased support for the development and commercialisation of technologies reducing greenhouse gas emissions.

The greenhouse gas emission reduction targets were set for the year 2030. In addition, it was requested that during 2008–2012 Finland should meet the Kyoto obligation of emission stabilisation at the 1990 level. The stringency levels studied in the scenarios were -10%, -20% and -30% from the 1990 level. Scenarios were calculated considering all six greenhouse gases of the Kyoto protocol. The EFOM model was used to find the cost-optimal allocations of the emission reductions with the alternative technological scenarios and the resulting air pollutant emissions ($SO_x$, $NO_x$ and particles) under the cost-optimal greenhouse gas reduction solutions.

## 4 Results

### 4.1 Development of particulate emissions under GHG reductions in Finland

Small-scale combustion and transport (including off-road machinery) are presently the dominating sources of particulate emissions in Finland (Figure 2). In the transport sector, diesel engines are the dominating source of particulates. Particulate emissions from the transport sector are expected to decline considerably in the future due to the progressively tightening emission limits for new vehicles specified by the EU (European Commission 2000). Figure 2 shows the development of particulate (TSP) emissions in Finland from the year 2000 to the year 2030 with the 'Conventional' and 'Optimistic' scenarios with a -20% greenhouse gas reduction requirement by 2030. In the calculations it was assumed that all small-scale furnaces and boilers would be continuously replaced with modern technology with a time cycle of 20 years. This assumption causes the significant decline in particulate emissions from the domestic and services sector. In Figure 2, also the calculated effect of tighter vehicle emission limits from the present to the year 2030 can be seen.

For all large-scale facilities, it was assumed that the present legislation and technology levels would be maintained also in the future, and no simultaneous improvement would take place. Therefore, there are no significant decreases in the calculated emission scenarios from large-scale sources. This should be viewed as a conservative (upper) estimate.

Figure 2 shows that structural GHG reduction measures alone do not warrant simultaneous particulate emission reductions. This is caused by the fact that large-scale combustion plants are already equipped with efficient particulate emission controls in Finland, and a shift towards smaller-scale combustion of biomass may actually increase particulate emissions unless advanced control technologies are employed.

### 4.2 Development of sulphur emissions under GHG reductions in Finland

In Finland, sulphur emissions have been cut very significantly during the 1980's and the 1990's. In 2000, the national sulphur emissions were 74 kilotonnes $SO_2$ (Statistics Finland 2001), which corresponds to a -87% change from the peak level of 582 kilotonnes $SO_2$ in 1980. Presently, all large-scale facilities causing sulphur emissions are equipped with effective flue gas scrubbers. Also the use of high-sulphur fuels has been cut substantially. This means that large further emission reductions are difficult to obtain and that technical measures typically have high unit reduction costs. This implies also that structural changes in energy production may not have very large effects on total sulphur emissions. Figure 3 shows the calculated effect of greenhouse gas emission reductions by 2030 compared to present.

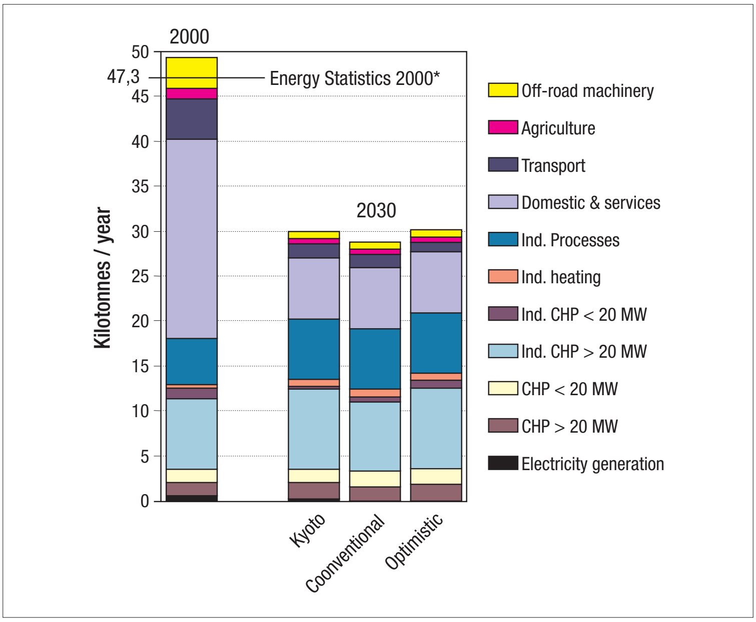


**Figure 2.** Finnish particulate (TSP) emissions in 2000 and in 2030 with the ‘Conventional’ and ‘Optimistic’ scenarios with a -20% greenhouse gas reduction requirement. The situation in 2030 with GHG emission stabilisation at 1990 level (‘Kyoto’) is shown for comparison.

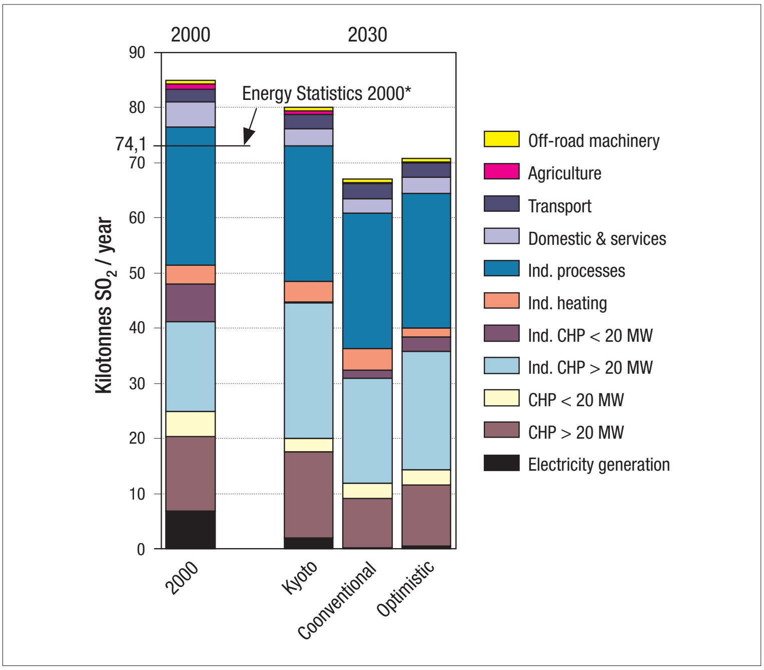


**Figure 3.** Finnish sulphur emissions in 2000 and in 2030 with the ‘Conventional’ and ‘Optimistic’ scenarios with a -20% greenhouse gas reduction requirement. The situation in 2030 with GHG emission stabilisation at 1990 level (‘Kyoto’) is shown for comparison.

The large difference between the modelled emissions for 2000 and statistics is due to the exceptionally warm winter and subsequently low use of coal in 2000, whereas the EFOM model seeks to represent only long-term average conditions. A gradual small decrease of sulphur emissions takes place already with the 'Kyoto' scenario. The -20% GHG scenarios ('Conventional' and 'Optimistic') yield a 11–16% structural reduction in total sulphur emissions in comparison to 'Kyoto'. This is due to the diminished use of sulphur-containing fuels, mainly coal and peat.

### 4.3 Development of $NO_x$ emissions under GHG reductions in Finland

Presently, Finnish $NO_x$ emissions are dominated by emissions from the transport sector (including off-road machinery). Emissions from transportation are expected to decline considerably in the future due to the progressively tightening emission limits for new vehicles specified by the EU (European Commission 2000). Figure 4 shows the calculated development from the year 2000 to 2030 with the different GHG scenarios.

The difference between modelled emissions for 2000 and statistics is explained by the fact that the modelled emissions from the transport sector are based on a recent update of the LIISA model (Mäkelä 2002). This update has been done after the 2001 official statistics shown in Figure 4.

The expected decline of emissions from the transport sector (including off-road machinery) causes the significant drop in total $NO_x$ emissions in all scenarios. The -20% GHG scenarios ('Conventional' and 'Optimistic') yield a 8–9% structural reduction in total $NO_x$ emissions in comparison to 'Kyoto'. This is mainly due to the penetration new technologies in the transport sector, such as hybrid

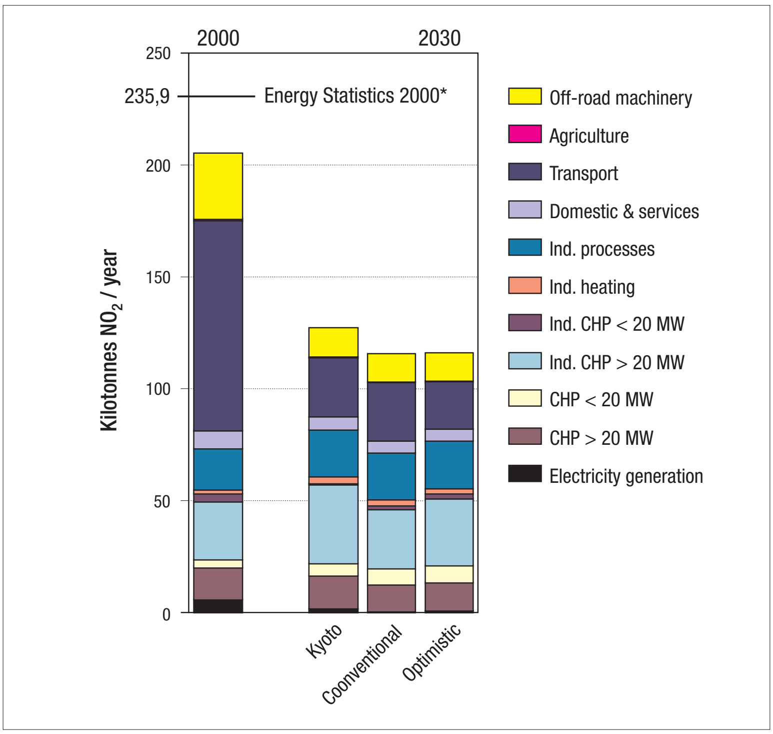


**Figure 4.** Finnish $NO_x$ emissions in 2000 and in 2030 with the 'Conventional' and 'Optimistic' scenarios with a -20% greenhouse gas reduction requirement. The situation in 2030 with GHG emission stabilisation at 1990 level ('Kyoto') is shown for comparison.

engines and fuel cells, in the 'Optimistic' scenario after the year 2020. In the 'Conventional' scenario, the decrease in total $NO_x$ emissions is caused by the smaller total energy use in the energy and industrial sectors. This decrease is partly offset by the remaining larger emissions with the conventional technologies in the transport sector.

## 5 International results

In addition to the model study for Finland reported above, a literature review of similar studies for other countries and regions was conducted. The results for Finland reported here were compared with the corresponding results from other countries to gain insight into the general mechanisms and country-specific circumstances determining the magnitude and characteristics of the side effects. Knowledge of general mechanisms and regional circumstances is also necessary for understanding the implications of the side effects and ancillary benefits for the export possibilities of Finnish GHG mitigation technologies.

For the EU, analyses on the ancillary benefits of implementing the Kyoto protocol have been reported (*e.g.*, Barker and Rosendahl 2000, Syri *et al*. 2001). The different studies have come up with very similar results. Structural reductions of 12–20% and 7–10% in sulphur and $NO_x$ emissions, correspondingly, can be expected in the EU-15 region by the year 2010 with the implementation of the Kyoto protocol. The ancillary benefits in VOC and particulate emissions reductions were estimated smaller, in the order of 4%. One reason for the small expected relative benefits is that a substantial part of the anticipated GHG reduction measures, such as shifting to biomass fuels, also produces significant amounts of VOC and particulate emissions. Secondly, a major part of VOC emissions in the EU is caused by industrial activities, and they are thus not directly affected by GHG reduction measures targeting largely the production and end-use of energy.

Analyses on the ancillary benefits of larger long-term GHG emission reductions in the OECD countries have yielded similar results (ECN-RIVM 2000, IEA 2002). Studies extending to the environmental impacts and especially to health benefits gained with GHG mitigation activities have indicated that very significant benefits in reduced health hazards can be gained by shifting to cleaner fuels and more modern energy production technologies (Davis *et al*. 1997, Cifuentes *et al*. 2001a, b). Replacement of old coal-fired coal combustion plants with inadequate emission control by cleaner and more modern technologies is often is a key position in the reduction of particulate air pollution.

Especially in developing countries, the significant improvements in local environmental conditions achieved with cleaner technology may actually be more decisive implementation factors than the expected GHG reductions. This may actually boost considerably the global demand for those GHG mitigation technologies, which offer solutions also for, *e.g.*, local air pollution.

## 6 Conclusions

Scenario studies with the EFOM model indicated that structural changes in the Finnish energy and industrial system needed to achieve substantial GHG reductions would induce significant side benefits in reduced sulphur and nitrogen oxides emissions. The -20% GHG restriction scenarios yielded a 11–16% structural reduction in total sulphur emissions in comparison to the 'Kyoto' scenario. The main mechanism causing structural reduction in sulphur emissions is the diminishing use of sulphur-containing fuels, mainly coal and peat. $NO_x$ emissions would decrease by 8–9% from the 'Kyoto' scenario. This is mainly due to the penetration of new technologies in the transport sector, such as hybrid engines and fuel cells, in the 'Optimistic' scenario after the year 2020. In the 'Conventional' scenario, the decrease in total $NO_x$ emissions is caused by the smaller total energy use in the energy and industrial sectors. This decrease is partly offset by the remaining larger emissions with the conventional technologies in the transport sector.

The study indicated that structural GHG reduction measures alone do not warrant simultaneous particulate emission reductions. This is caused by the fact that large-scale combustion plants utilising fossil fuels are equipped with very efficient particulate emission controls in Finland, and a shift towards smaller-scale combustion of biomass may actually increase particulate emissions unless advanced control technologies are employed.

The results obtained for Finland in this study are well in accordance with corresponding studies from other countries and regions. The largest relative benefits in the present situation can be expected in the reduction of sulphur and $NO_x$ emissions. Also significant ancillary benefits in the reduction of particulate emissions are possible, but they require application of advanced combustion technology, especially if substantial use of biomass-based fuels in small- and medium–scale installations is planned as a GHG mitigation measure. As the increased use of biomass-based fuels is one key GHG mitigation measure planned in many industrial countries and the general recognition of the health hazards of particulate pollution is growing, this may actually promote significantly the export opportunities for the advanced Finnish technological knowledge and solutions in biomass utilisation. Especially in developing countries, the significant improvements in local environmental conditions achieved with cleaner technology may actually be more decisive implementation factors than GHG reductions. This may boost significantly the global demand for those GHG mitigation technologies, which offer solutions also for, *e.g.*, local air pollution.

Especially the estimation of fine particle emissions is fraught with many uncertainties. Only the emissions from large point sources, which are required to continuously monitor their emissions, can be considered rather reliable. Emissions from small-scale combustion, in turn, can vary very much depending on the combustion conditions, fuel quality and the operation of possible emission reduction installations. The average emission levels of domestic furnaces in Finland are presently poorly known. Further research, especially measurement campaigns, would be needed for better estimates of the present emission levels and future reduction possibilities.

## Publications and reports made under the project

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