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Analysis and Evaluation of the Triptych 6

Case Finland

Sampo Soimakallio
VTT, Finland

Adriaan Perrels & Juha Honkatukia
VATT, Finland

Sara Moltmann & Niklas Höhne
ECOFYS, the Netherlands

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tel. växel 020 722 111, fax 020 722 4374

VTT Technical Research Centre of Finland, Vuorimiehentie 5, P.O.Box 1000, FI–02044 VTT, Finland
phone internat. +358 20 722 111, fax +358 20 722 4374

VTT, Biologinkuja 7, PL 1000, 02044 VTT
puh. vaihde 020 722 111, faksi 020 722 7026

VTT, Biologgränden 7, PB 1000, 02044 VTT
tel. växel 020 722 111, fax 020 722 7026

VTT Technical Research Centre of Finland, Biologinkuja 7, P.O. Box 1000, FI-02044 VTT, Finland
phone internat. +358 20 722 111, fax +358 20 722 7026

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Soimakallio, Sampo, Perrels, Adriaan, Honkatukia, Juha, Moltmann, Sara & Höhne, Niklas

Title

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Abstract

The post-2012 global climate policy framework is being discussed in various fora. The Finnish Ministry of the Environment has commissioned several studies on various elements of the future climate framework with a view to both preparing for the international fora and informing the national discourse. This report covers the second phase of a two-phase study, which focuses on the perspectives for long-term emission reduction pathways and the possible implications for long-term reduction targets by country or by groups of countries.

The objective of this 2nd phase of the study was to improve the understanding of more complex approaches, such as Triptych and Multistage in their computational context, and moreover as operationalized by Ecofys in 'the Evolution of commitments' tool (EVOC). Critical input data, parameters and assumptions of the global Triptych approach, notably those relevant for Finland, were identified. The sensitivity of the approach was then tested by varying the values for those critical data and parameters in test runs carried out by Ecofys. The results of the test runs were analysed by Ecofys and reviewed by VTT and VATT. Furthermore, VTT and VATT made an overall assessment, including conceptual considerations, of the applicability of the Triptych approach for burden sharing in long-term emission reductions.

The implemented sensitivity calculations of the Triptych 6 system indicated a variation of less than 10 percentage points from original runs carried out in the 1st phase of the study. Most of the test runs resulted in decrease, whereas only a few test runs led to increase, of emission allowances of Finland. The impact was stronger in 2020 than in 2050. However, the test runs were restricted by the methodology that was not much modified. More significant variations could have been caused by implementing methodological changes. As regards the review of the model VTT and VATT identified the following critical methodological features of the Triptych 6 system:

- the chosen representation of CHP in the model
- the sensitivity of base year selection with regard to fuel mix and growth of electricity production
- the lack of distinction between energy-intensive and other manufacturing industry
- per-capita-based emission indicators as sole drivers for handling the domestic sector
- the pre-fixation of all key-drivers (such as growth of GDP and electricity demand) and subsequent adaptation of some key parameters to facilitate target achievement without any recourse to relative cost

Keywords
burden-sharing, climate policy, greenhouse gases, climatic change, emissions reduction, emissions allowances, Triptych 6, Multistage, emissions indicators, Finland

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Preface

The Finnish Ministry of the Environment has commissioned several studies on various elements of the future climate framework with a view to inform the national discussions. This report covers the second phase of a two-phase study, which focuses on the perspectives for long-term emission reduction pathways and the possible implications for long-term reduction targets by country or by groups of countries. The second phase of the study was carried out by Ecofys, VTT, and VATT in two separate, but closely linked projects.

The steering group of the project between Finnish Ministry of Environment, VTT and VATT was formed by Counsellor Outi Berghäll from the Finnish Ministry of the Environment, Research Professor Ilkka Savolainen from VTT, and Research Director Juha Honkatukia from VATT.

The report was written by Research Scientist Sampo Soimakallio from VTT, Principal Economist Adriaan Perrels and Research Director Juha Honkatukia from VATT, as well as by Consultant Sara Moltmann and Manager Niklas Höhne from Ecofys GmbH. The report only reflects the views of its authors and hence does not constitute a formal viewpoint of the Finnish Ministry of the Environment.

Contents

1. Introduction

The ultimate objective of the United Nations Framework Convention on Climate Change (UNFCCC) is to stabilize greenhouse gas concentrations in the atmosphere at a level that prevents dangerous anthropogenic interference with the climate system. The Kyoto protocol to the UNFCCC, which came into force on 16 February 2005, is the first step that has been taken reaching this ultimate objective. Under the Kyoto Protocol, the so-called Annex I countries, have binding greenhouse gases (GHG) commitments for the period 2008–2012 to limit or reduce their greenhouse gas emissions. Much greater emission reductions than those agreed in the Kyoto Protocol are, however, needed to reach the ultimate objective of the UNFCCC.

Although much work needs to be done to deliver the commitments of the Kyoto Protocol, the focus in the international climate negotiations is increasingly shifting towards a framework for future climate action. The challenge is to find a solution that is environmentally effective and economically efficient, and leads to the widest possible participation in line with common but differentiated responsibilities and respective capabilities.

The post-2012 climate framework is being discussed in various forums: between parties to UNFCCC and the Kyoto Protocol in formal and informal settings, and by many research organizations and NGOs (including both business and environmental organizations). The discussions under UNFCCC and the Kyoto Protocol are only beginning and are expected to proceed relatively slowly and, at the beginning, to focus more on the process of the negotiations. Thus, the content of the future framework is discussed mainly in various informal forums and in various studies.

At the general level, these discussions and studies have relatively similar views on the key issues and elements of the future climate framework. The report of the climate dialogue at Pocantico, for example, suggests that an effective future framework needs to:

- engage major economies
- provide flexibility
- couple near-term action with long-term focus
- integrate climate and development
- address adaptation
- be viewed as fair.

According to the report, approaches that might serve as elements of future international efforts include:

- aspirational long-term goals (initially based on governments' own visions and other actors rather than a negotiated quantified long-term target)
- adaptation (assistance to support the development of national adaptation strategies and help highly vulnerable countries cope with urgent adaptation needs; consideration of climate change impacts in investments)
- targets and trading (it is suggested that emission targets coupled with international emissions trading remain a core element of the multilateral effort; future targets could vary in time, form, and stringency; market-based approaches could include a mechanism crediting policy-driven emission reductions in developing countries)
- sectoral approaches (commitments structured around key sectors such as power, transportation or land use could take a variety of forms: emission targets, performance- or technology-based standards, or "best practice" agreements)
- policy-based approaches (countries could commit to broad goals integrating climate and development objectives, then pledge national measures to achieve them and report periodically on implementation and results)
- technology cooperation (governments could coordinate and increase support for research and development of long-term technologies; stronger cooperation is also needed to facilitate the deployment of clean technologies in developing countries).

The Finnish Ministry of the Environment has commissioned several studies on various elements of the future climate framework with a view to informing the national discussions.

This report covers the second phase of a two-phase study, which is related to the long-term emission reduction pathways and the possible implications for long-term reduction targets by country or by groups of countries. Several approaches (so-called "burden sharing models") have been suggested by various organizations to divide the global emission reduction requirement between countries and group of countries. These approaches are based on various principles and have various degrees of complexity. More complex approaches can be regarded as combined top-down and bottom-up approaches. They start with the GHG stabilization level and the global emission reductions that are needed to reach that level. The burden sharing is carried out by using a bottom-up approach to take into account the differences between countries and their national circumstances.

The first phase of the study "Implications of proposals for international climate policy after 2012 on Finland" was carried out by Ecofys in early 2005. In the study, national greenhouse gas emission allowances for 35 countries/country groups were calculated for 2020 and 2050 for three stabilization levels and three approaches. The approaches were Contraction and Convergence by 2050 and 2100, Multistage and Triptych, and the stabilization levels were 550 ppmv, 450 ppmv and 400 ppmv CO_2.

The second phase of the study focused on the methodological issues. It was set up to gain improved understanding of the more complex approaches: Triptych and Multistage. The objective was to identify the critical input data, parameters and assumptions and estimate their impact on the results. At a more general level, the aim was also to evaluate the current advantages and disadvantages of the complex approaches and possibilities for their future improvement, and based on this to discuss their current and future use in the making of climate policy and international negotiations.

The second phase of the study was carried out by Ecofys, VTT and VATT in two separate, but closely linked, projects. VTT and VATT familiarized themselves with the Triptych approach as it is operationalized in Ecofys's EVOC tool, and analyzed the results of the first phase of the study to identify the critical input data, parameters and assumptions that could have a significant impact on the results. The results of this work are presented in section 3.1. Ecofys, VTT, VATT and the Ministry of the Environment together developed a test plan to find out about the impact of the identified issues on the results. The test runs were carried out by Ecofys. These results are presented in section 3.2. Chapter 4 contains VTT's and VATT's evaluation of the Triptych approach and its implementation in the EVOC tool. General conclusions and discussion on the current and future use of the complex approaches in the making of climate policy and international negotiations are presented in chapter 5.

2. Application of the Triptych 6 in estimating future commitments: Case Finland

2.1 Description of the Triptych 6

2.1.1 Origin and purpose of the approach

The Triptych approach is a method of sharing emission allowances among a group of countries, based on sectoral considerations. The Triptych approach was originally developed at the University of Utrecht (Blok et al. 1997) to differentiate the emission allowances between Member States of the EU for the First Commitment Period of the Kyoto Protocol. Only CO_2 emissions from fossil fuel combustion activities were considered and three different emission categories were distinguished in the original version: the power sector, energy-intensive industries, and all the rest together as the 'domestic sector'. The selection of these categories was based on a number of differences in national circumstances raised in the negotiations that were relevant to emissions and emission reduction potentials: differences in standard of living, in fuel mix for the generation of electricity, in economic structure and in the competitiveness of internationally-oriented industries.

In the following years, the approach has been extended on a global scale and includes more sectors and gases. Heleen Groenenberg (2002) from the University of Utrecht presented an update in her PhD thesis which was later implemented in the RIVM FAIR Model (Den Elzen and Lucas 2003). In addition, Ecofys provided a slightly different global update in Höhne et al. (2003). On the basis of a review of existing Triptych methodologies, Ecofys developed a new version of the approach, version 6.0 (Phylipsen et al. 2004). During the present study, some modifications were made to the methodology resulting in version 6.1.

Approaches such as Triptych are part of a larger international discourse on long-term emission scenarios, which started in the late 1990s (Blanchard et al. 2003; den Elzen et al. 2003; Criqui and Kouvaritakis 2000). The various model explorations arise from the need to obtain insights about the long-term prospects of emission reduction policies at a global level. As already indicated in the introduction, there is a widely shared view that over the course of the 21st century greenhouse gas emissions should be drastically reduced in order to avoid very risky degrees of climate change. There are many ways in which these emission reductions can be brought about (Blok et al. 2005), whereas resulting alternative pathways depend on criteria such as progress in abatement technologies and carbon-free alternatives, cost efficiency, and equity within and across countries. The intention is to try to find the best possible mix of intertemporal cost efficiency and cross-sectional and intertemporal equity. Such an assessment is, however, very complex and problematic when applied to long time spans, whereas global coverage is hard to combine with sufficient detail by country (group). Complex models, such as FAIR model system and POLES model have been developed to carry out such assessments. The adequate running of an additional alternative policy scenario with these complex models requires considerable effort[1].

In contrast, Triptych purports to contribute to long-term policy design by offering a simplified but comprehensive greenhouse gas emission attribution system, which attempts to take both equity and technical-economic ability to reduce emissions into account. Thanks to the simplifications, comprehensive emission pathways up to 2100 can be produced fairly quickly for various alternative scenarios. Modifications within a given scenario can be implemented without too much effort.

2.1.2 Overall model structure and basic design principles

Countries are allotted to a category based on their GDP per capita. For each group of countries the growth rates of the population, GDP, electricity demand, energy efficiency etc. are pre-fixed by sector, by country (group) and by period. Countries will have their growth rates of industrial output and electricity demand adapted in accordance with the wealth category to which the country is allotted (see sections 2.1.4 and 2.1.5). The consistency of these sets of growth rates is assumed to be validated prior to their use in the EVOC database. Model users can however override the default values and insert alternative country-specific values.

Included growth rates are those for:

- population (relevant for GDP per capita and growth in the 'domestic sector')
- GDP per capita (influences the emission pathways of agriculture and waste respectively)
- electricity demand
- energy efficiency (in industry, not affecting electricity demand)
- industrial output (in value terms)
- industrial structure (to weigh in evolution of e-intensity per unit of value)
- directly inserted emission pathways for agriculture.

In short, the resulting pathways are in fact premeditated and do not include any kind of responsiveness as the reduction process unfolds.

[1] . In chapter 4, sections 4.1 and 4.2, there is more discussion about comparison with alternative models.

2.1.3 Input data and sectoral split

The basic input data and the division of the sectors to calculate the emission allowances are based on the Evolution of commitments tool (EVOC) developed at Ecofys (see Appendix A). The EVOC tool contains historical and scenario emission data for all greenhouse gases considered in the Kyoto Protocol (CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6) for 192 individual countries.

The emission sectors distinguished in the EVOC tool are as follows:

- the power sector
- industry
- domestic sectors, including:
    - services
    - private homes
    - road, rail and inland shipping
    - international transport (bunker fuels) (optional)
- fossil fuel production
- the agricultural sector
- waste disposal and processing
- land use change and forestry (optional).

The user can select whether to consider only CO_2, or CO_2, CH_4 and N_2O, or all six gas groups. In addition, the emissions from international transport and CO_2 emissions from land-use change and forestry can be included or excluded at the discretion of the user. The user can also make some specifications concerning the data sources used.

Historical emissions are mainly based on UNFCCC submissions and data from the International Energy Agency. Future reference emissions are based on the IPCC Special Report on Emission Scenarios known as SRES scenarios (IPCC 2000). As SRES scenarios are only available at regional level[2], the EVOC tool selects the growth assumption for each sector and for each gas in accordance with the group the country belongs to. Thus, the background assumptions behind the emission data, such as the development of population, GDP, or electricity demand, are mean values given on a regional (not national) level.

The emission development by 2010 has been assessed by using a slightly different method for Annex I countries. As a default setting, all Annex I countries (including the USA) are assumed to reach their Kyoto target in 2010. The required emission reductions from the reference scenario to reach those targets are assumed to be implemented

[2] Regions considered: 1) Canada, 2) USA, 3) Central America, 4) South America, 5) Northern Africa, 6) Western Africa, 7) Eastern Africa, 8) Southern Africa, 9) OECD Europe, 10) Eastern Europe, 11) Former USSR, 12) Middle East, 13) South Asia, 14) East Asia, 15) South East Asia, 16) Oceania, 17) Japan

equally within all sectors, excluding the domestic sector which follows its own reference scenario. In addition, the user can select two alternative options for Annex I countries: for the USA to reach its national target or reference scenario, and for the others to reach the lower of either their Kyoto target or their reference scenario, or just the reference scenario. All Non-Annex I countries follow their reference scenario until 2010. The years between the latest statistical year available (2001) and 2010 are linearly interpolated.

2.1.4 Power sector

The emission allowances of the power sector are calculated for each country by determining the development of the amount, structure and efficiency of electricity production. The effects of imports and exports of electricity are not considered, since the Triptych approach builds on the reporting guidelines for national greenhouse gas emission inventories, which stipulate that all eligible emissions occurring in the territory of the reporting country are to be reported. In the context of that logic, the purpose of the emissions-causing production, i.e. domestic or export, is irrelevant. The implication of this assumption is that the consumption of and production of electricity within a country are assumed to be equal throughout the considered period.

The initial electricity generation amount and fuel basis for the statistical years (1990–2001) is taken from the IEA energy statistics supplying data for 66 countries making up 90% of global emissions. For countries where the fuel mix in power generation is not available, the Triptych method is not calculated for the electricity sector, but the respective reference emissions are used for electricity.

<u>Growth</u>

The concept of the Triptych approach for the electricity sector is to allow growth in production but to require an improvement in efficiency and a shift to less carbon-intensive fuels. To determine the growth rates for the purpose of distributing emission allowances in the Triptych 6 system, one could either use desired or normative growth rates (more increase allowed in less developed countries) or descriptive growth rates from scenarios (possibly very low for some countries, e.g. in Africa, and high for others, e.g. China). The Triptych 6 system takes a method in between, starting from scenarios but adjusting the growth depending on the state of development of the country.

The assumed growth of electricity production starting from the latest year available in IEA energy statistics (2001 in the model) is derived from SRES scenarios by applying certain correction factors. Countries have been differentiated into four groups on the basis of GDP per capita, and the scenario-derived growth rates have been adjusted by the factors presented in Table 1. The scenario-derived annual growth rate will be reduced and increased by a certain percentage for countries with a higher or lower GDP per capita level, respectively. Medium GDP per capita countries are not adjusted.

Table 1. GDP_{ppp} per capita groups.

Group	GDP per capita [US$(1995)/cap/a]	Correction factor (x = 0...1)
Very Low	0–2000	+2x %/a
Low	2001–7000	+ x %/a
Medium	7001–15000	0 %/a
High	15001–>	-x %/a

As GDP per capita levels evolve over time, countries may progress from a lower to a higher group. The model reflects this in a 5-year interval in the growth rate adjustments applied to the different regions. If more than half of the global population is classified as having high GDP per capita levels, the adjustment made to the scenario's growth rate is cut in half within the high GDP per capita group.

A limit is set on how much the total global sector growth using the differentiated growth rates may deviate in 2100 from that given in the reference scenario. Similarly, the maximum deviation in 2100 at the country level can be defined by the user. The program iteratively selects the set of adjustment factors that are the highest possible between 0% and 1% without violating the boundary conditions.

Structure

The power production structure considered in the model is as follows:

1) Combined heat and power production (CHP)
2) Coal condensing power
3) Gas condensing power
4) Nuclear power
5) Oil condensing power
6) Renewable energy sources.

The model takes the fuel mix of power production for statistical baseyears from the IEA's energy statistics. Only the fuel mix (coal, gas, oil, nuclear, renewable) is considered at this stage, and any difference between production technologies, such as CHP or condensing power production, is not made (i.e. CHP equals zero). The fuel mix in 2010 is assumed to be the same as in the latest available statistical year (here 2001).

The power production structure from 2010 onwards is defined by setting the assumptions of development for all six of the above-mentioned production forms.

- The absolute or relative share of nuclear power production is assumed to remain at the level of 2010.

- The share of renewables (e.g. 60% in 2050) and natural-gas-fired-CHP-production (e.g. 30% in 2050) in total electricity production is assumed to be equal in each country in certain year(s). The default convergence year is 2050. Shares up to the first view year and between view years are determined by linear interpolation.

- The share of solid and liquid fossil fuels in total electricity production is assumed to decline to the user-defined percentage from the baseyear level (e.g. 75% lower in 2050 compared to 2010). The default target year is 2050. Reduction percentages up to the first view year and between view years are determined by linear interpolation.

- The remaining share of electricity production in view years is assumed to be produced by natural-gas-fired condensing power. If the overall share of other sources covers more than 100%, the shares of renewables and CHP are reduced by a weighted ratio to reach a total share of 100%.

Efficiency

The conversion efficiency in power production is determined by using specific emission factors for each form of fossil-fuel-based electricity production (coal, oil, gas, CHP) by each year. As regards statistical years, the country-specific emission factors are calculated by dividing the fuel-specific emissions of the energy industry by the fuel-specific electricity production amount. The emission factors in 2010 are those provided by the IEA for the last available statistical year, but adjusted so that the emissions in 2010 from the electricity sector match the selected reference scenario.

The specific emission factors beyond 2010 are calculated by using the IEA's fuel-specific emission factors, which are divided by the assumed efficiency of the production form (Table 2). The emission factors are given in terms of g CO_2/kWh_e. The efficiencies of production forms are set to be the same in each country in given view years. Emission factors up to the first view year and between view years are determined by linear interpolation. As a default assumption, the emission factor of CHP is assumed to be 70% that of gas.

Table 2. Fuel-specific emission factors used in the Triptych 6 system (Phylipsen et al. 2004).

Carrier / combustion technology	Carbon content of fuel (fixed) in g CO_2/kWh_f)	Efficiency (%)	Specific emission factor (g CO_2/kWh_e)
CHP	202	X	202/X
coal	342	X	342/X
gas	202	X	202/X
oil	263	X	263/X

2.1.5 Industry

In the Triptych 6 system the industrial sector consists of manufacturing industry and construction. The industrial sector is handled in its entirety without making any difference between energy-intensive and light industry, due to lack of data.

The emissions from the industrial sector are calculated by multiplying the base year emissions by the development of activity giving rise to emissions, and by the improvement in energy efficiency. Activity having an impact on energy consumption is described with two parameters: the development of industrial value added (IVA), i.e. production in monetary terms, since production growth in physical terms is not available; and the structural change.

Production growth and structural change

The development of industrial value added (IVA) is derived like the production of electricity, by adjusting the scenario-derived values with the correction factors presented in Table 1 and explained in Chapter 2.1.4. As the IVA indicator includes all industrial activities expressed in monetary terms, the production is multiplied with a structural change factor that indicates that the IVA grows faster than physical production. This is partly due to the change from energy-intensive to lighter industry. The value of the structural change index is assumed to equal 1 in the selected base year, and linearly decrease to the user-defined value in the selected view year in all countries. For example, a decrease in the index value from 1 in 2010 to 0.3 in 2050 means that over 40 years of convergence, the growth in industrial value added is reduced by around 1 percentage point per year.

Energy efficiency

The energy efficiency of industry is assumed to improve and converge in all countries in a certain year, and to improve beyond that. The efficiency is represented by an energy efficiency index (EEI). As the energy efficiency index is multiplied, similarly to the IVA and the structural change index, directly by baseyear emissions, the indicator includes a decarbonisation assumption, i.e. the shift to less carbon-intensive fuels in industry.

The chosen energy efficiency indices for the base year are those presented by Groenenberg (2002). These regional EEIs are used for all countries within that region (Table 3). Energy efficiency indices converge from their current level to user-defined levels in (2030), 2050, and 2100. Efficiency indices up to the first view year and between view years are determined by linear interpolation. For example, by setting the value of the EEI to equal 0.4 in 2050, the carbon intensity of industry should decrease to third and fifth in OECD-Europe and the most inefficient countries, respectively (Table 3).

Table 3. Regional Energy Efficiency Index based on Groenenberg (2002) used for the base year in the Triptych 6 system.

	Region	EEI
01	Canada	1.3
02	USA	1.8
03	Central America	1.5
04	South America	1.5
05	Northern Africa	1.6
06	Western Africa	1.6
07	Eastern Africa	1.6
08	Southern Africa	1.6
09	OECD Europe	1.2
10	Eastern Europe	1.7
11	Former USSR	2.0
12	Middle East	1.6
13	South Asia	1.7
14	East Asia	1.9
15	South East Asia	1.6
16	Oceania	1.7
17	Japan	1.3

2.1.6 Domestic sector

The domestic sector in the Triptych 6 system covers the residential, commercial, and transport sectors, as well as energy-related CO_2 emissions from agriculture and F-gas emissions. The emissions per capita are assumed to converge globally by the user-defined convergence year (beyond 2010) and to remain stable after that. Per-capita emissions from the current level up to the convergence year are determined by linear interpolation. Total emissions in the domestic sector are determined by multiplying the per-capita emissions for each year with the population for that year, according to the reference scenario.

2.1.7 Fossil fuel production

Emissions from the fossil fuel production sector are assumed to decrease from the level of the selected base year by a user-defined percentage and convergence year (beyond 2010), and remain stable after that. This requirement is the same for all countries. Emissions up to the convergence year are determined by linear interpolation.

2.1.8 Agricultural sector

The reference scenarios for non-energy-related emissions from agriculture determined in the EVOC tool represent significant growth and stabilisation between 2000 and 2050 for developing and industrialised countries, respectively. The stabilisation of these emissions in developing countries is assumed to take place during 2051–2100. In the Triptych 6 system, these emissions are reduced by a user-defined reduction percentage below reference in the view year for two groups of countries depending on their GDP per capita (groups 1–3 together and group 4 as determined for the adjustment for industry and electricity in Table 1). Higher emission reductions are required for the countries in the group with higher GDP per capita. Emissions up to the first view year and between view years are determined by linear interpolation.

2.1.9 Waste

Emissions from the waste sector are assumed to converge to a certain per capita level by a user-defined convergence year (beyond 2010). Per-capita emissions up to the covergence year are determined by linear interpolation. For subsequent years the per-capita emissions remain constant at the same level. Total emissions in the waste sectors are determined by multiplying the per-capita emissions for each year with the population for that year, according to the reference scenario.

2.1.10 Land use change and forestry

The EVOC model holds an option to include or exclude the emissions and sinks of land use, land use change, and forestry (LULUCF). According to the reference scenarios, the LULUCF sector globally represents an emission source (deforestation) in the first half of the century (particularly in Africa and South-America), while mostly a removal source (sequestration of carbon) in the latter half of the century (particularly in Africa and the former Soviet Union). In the Triptych 6 system, per-capita emissions from the LULUCF sector have to decrease to zero by a user-defined year (e.g. 2050). Emissions from this source are, however, highly uncertain and emissions estimates from various sources are often not consistent. Therefore, it has also been suggested that emissions from deforestation are treated with a different instrument, separate from other emissions.

2.2 The Triptych approach as part of the Multistage model

In a multistage model, countries participate in several stages with differentiated types and levels of commitments (Gupta 1998, Gupta 2003, den Elzen et al. 2003, Höhne et al. 2003, Michaelowa et al. 2003, Criqui et al. 2003, Ott et al. 2004, Höhne 2005). The multistage approach considered here is the same as that presented by Höhne and Ullrich (2005), who separate it into three different stages as follows:

- Stage 1 - No commitments: Countries with a low level of development do not have climate commitments. At least all of the least-developed countries (LDCs) would be in this stage. In the model, we implemented these countries following their reference scenarios, as no emission reductions are required.

- Stage 2 - Enhanced sustainable development: at the next stage, countries commit in a clear way to sustainable development. The environmental objectives are built into development policies. Requirements for such a sustainable pathway could be defined, e.g. that inefficient equipment is phased out and requirements and certain standards are met for any new equipment, or a clear deviation from the current policies, depending on the country. The implementation of such a sustainable development pathway has to be monitored and verified. The additional costs could be borne by the country itself or by other countries, e.g. official development aid supplemented by additional climate-related funds. This stage was implemented very simply in the model: these countries reduce emissions a percentage below their reference scenario within 10 years and then follow the reduced reference scenario.

- Stage 3 - Absolute emission targets: countries in stage 3 receive absolute emission targets and have to reduce absolute emissions substantially until they reach a low per-capita level. As time progresses, more and more countries enter stage 4. The Triptych approach can be used to set the binding emission reduction targets for the final stage(s) of the multistage model.

Countries move through these stages based on their level of emissions per capita. Since "followers do better" (they benefit from the technological developments of others), the threshold for entering stage 4 decreases linearly with time.

After each 10-year step, it is assessed whether a country should move to the next stage. Ecofys has introduced the condition that movement into stage 3 is only possible after a country has been at least one decade at stage 2. This is to avoid the situation that a developing country jumps from stage 1 directly to stage 3. Countries can jump from stage 1 to stage 2 immediately. Hence, all current Non-Annex I countries will be at maximum in stage 2 in 2020 and in stage 3 in 2030.

The free parameters (thresholds and reduction levels) are set in a way that resulting global emissions aim at 400, 450 and 550 ppmv CO_2 concentration in the long term. The exact calculation parameters used for different scenarios are presented in the report Höhne and Ullrich (2005).

2.3 Special characteristics of Finland

2.3.1 General

Finland is one of the northernmost countries in the world. In terms of land area it is Europe's seventh-largest, and the EU's sixth-largest, country. Forests cover four-fifths of the land area; only nine per cent is classified as agricultural land. The climate of Finland is cold, although on average several degrees warmer than in most areas at the same latitudes. The mean annual temperature is about 5.5°C in southwestern Finland, decreasing towards the northeast (UNFCCC 2001). Heating requirements can be high during the winter months. Heating degree-days, calculated according to a 17°C indoor temperature, vary in Helsinki from 3 400 to 4 800 per year. In Rovaniemi, in Lapland, the corresponding range is 5 500–7 000 (UNFCCC 2001). The heating of buildings corresponds to roughly one-fifth of the total primary energy consumption in Finland.

Increased concentrations of atmospheric greenhouse gases will have an impact on the climate. According to the climate scenarios prepared by the FINSKEN project, the climate will become warmer.

2.3.2 Power production structure

The energy production structure and related fuel mix is relatively diversified in Finland. In 2003, nuclear power corresponded to some 26% and hydropower to some 11% of overall electricity consumption. The rest of generation is based on combustion technologies using a wide range of fuels. The combined share of biofuels and waste fuels in production has increased steadily, corresponding together to some 14% in 2003 (Figure 1).

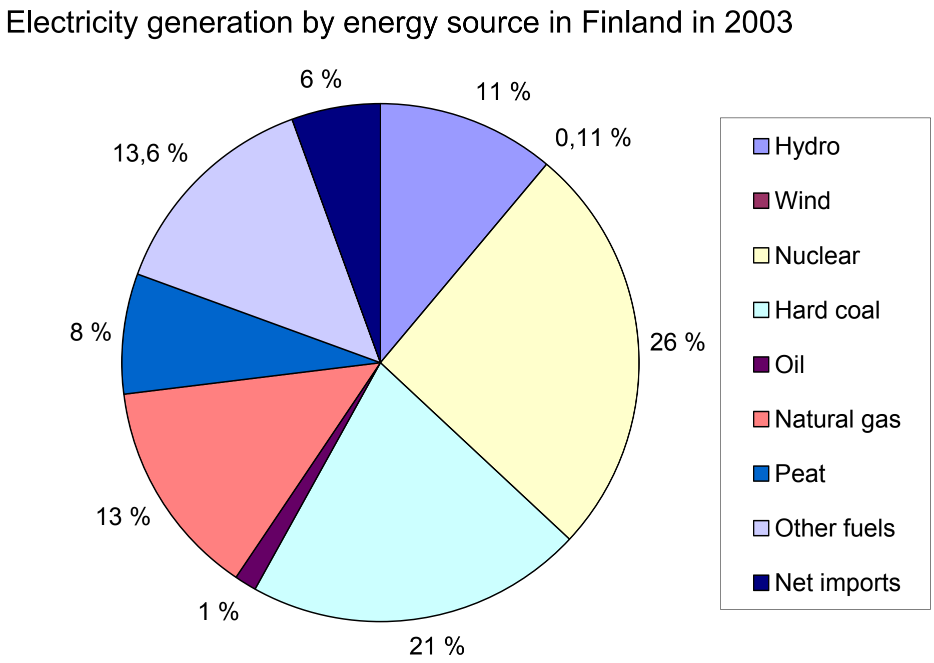


Figure 1. Electricity production by energy source in Finland in 2003.

Combined heat and power production (CHP) is extensively applied in Finland for both district heating and process industries. Currently, CHP generation in proportion to total electricity production equals some 35%, and over 50% in proportion to fuel-based electricity production. Consequently, the efficiency of electricity generation based on fuel combustion is exceptionally high in Finland (Figure 2). In addition, further possibilities to extend the utilisation of CHP and improve energy efficiency are much more restricted in Finland compared to many other countries.

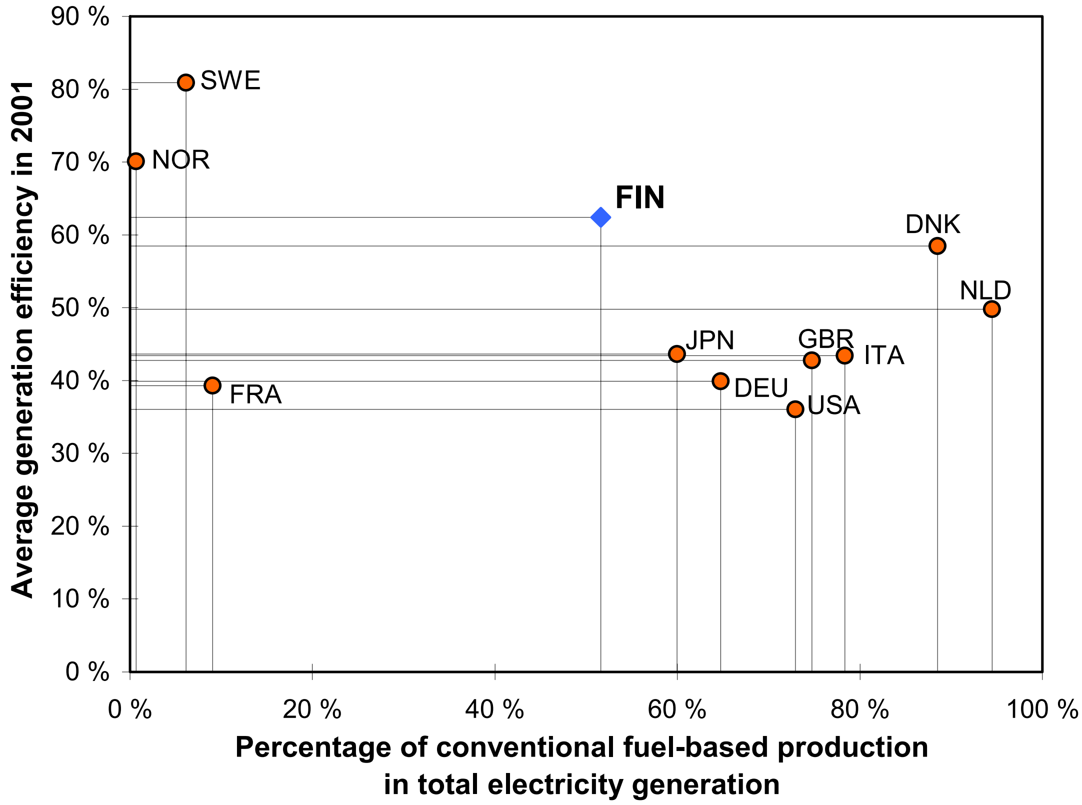


Figure 2. Average gross efficiency and scale of combustible-fuel-based electricity generation in selected OECD countries in 2001 (IEA 2003).

2.3.3 Industrial structure and electricity demand

The structure of industry is relatively energy-intensive in Finland. Currently, industry contributes to half of total primary energy consumption, and more than half of total electricity consumption. A considerable portion of energy-intensive industry is export-oriented. Thus, a lot of energy is used to supply other countries with energy-intensive products.

The growth of energy-intensive industry has been relatively strong in Finland after economic depression in the early 90s. In the original Triptych approach used for the EU's internal burden sharing, the development of energy-intensive industry was assumed to equal 1.1% annually in all non-cohesion countries, while there exist significant differences between countries in the structure of industry. Figure 3 below illustrates that this assumption has been, and is forecasted to be, a remarkable underestimate as regards growth in Finland between 1990 and 2010. Furthermore, as electricity demand and production was assumed to be independent from sectoral growth, e.g. industry, net electricity production figures were also underestimated in the original Triptych approach (Figure 4).

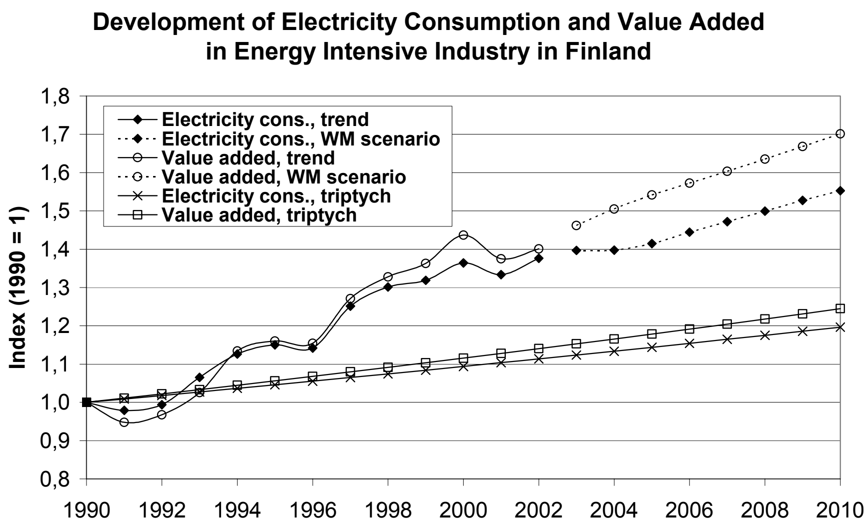


Figure 3. Development of electricity consumption and value added in energy intensive industry in Finland in 1990–2010, according to statistics and WM scenario assumption in comparison with Triptych assumption (Soimakallio et al. 2005).

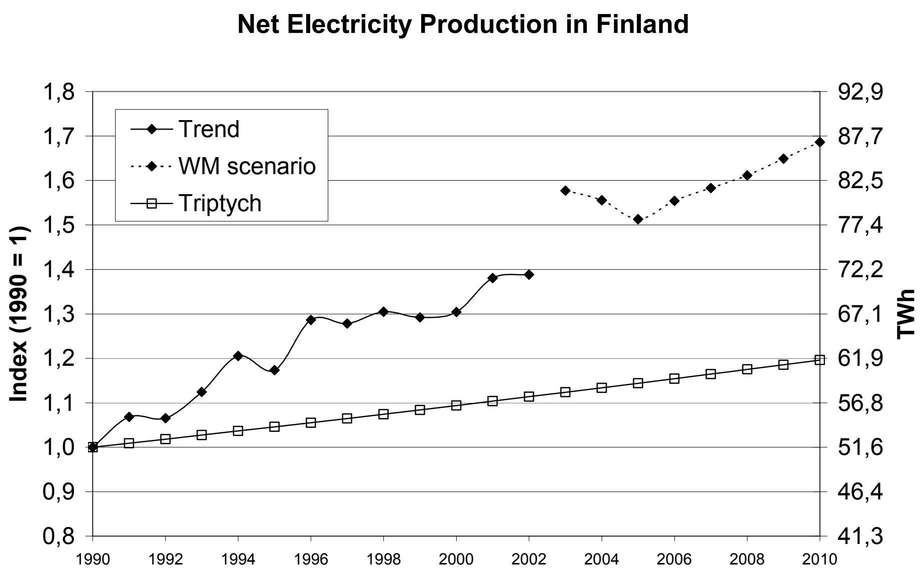


Figure 4. The development of net electricity production in Finland in 1990–2010, according to statistics and WM scenario assumption in comparison with Triptych assumption (Soimakallio et al. 2005).

The energy efficiency of Finnish industry has improved considerably since the 1970s, and is typically considered to be efficient in international comparisons. For example, in 1980–1990 industrial output rose by a third, while the consumption of energy only rose by some 20% (UNFCCC 2001). At aggregate levels of comparison this may not become evident however, since the share of energy-intensive industry in the entire industry portfolio is relatively large.

For *aggregate* economic growth the point of gravity is expected to continue to shift towards services and light industries. The share of energy-intensive industry in manufacturing output (expressed as the combined share of the paper, chemical and basic metals industry in total industrial gross value added) is, however, not decreasing very fast. Table 4 presents a summary of the trends. The SRES-FIN-A1 scenario, which allows for the most unhampered global trade, implies more growth in the sectors of advanced manufacturing and services, and consequently a slightly lower share for heavy industry. In the SRES-FIN-B1 scenario the somewhat slower growth in global trade affects in particular the advanced manufacturing and services sectors. In the SRES-FIN-A2 scenario with appreciably less growth in global trade, this effect gets even more obvious.

Table 4. Foreseen developments of the shares of heavy industry in gross national product and in total industrial gross value added in SRES-FIN-A1/B1/A2 scenarios.

Climate scenarios	**2000**	**2005**	**2025**	**2050**
SRES-FIN-A1				
share in industry's gross value added	10,8 %	10,4 %	10,0 %	8,3 %
share in total gross value added	41,3 %	36,7 %	35,7 %	35,2 %
SRES-FIN-B1				
share in industry's gross value added	10,8 %	10,4 %	10,0 %	9,4 %
share in total gross value added	41,3 %	36,8 %	36,1 %	43,8 %
SRES-FIN-A2				
share in industry's gross value added	10,8 %	10,5 %	10,6 %	9,6 %
share in total gross value added	41,3 %	37,5 %	39,5 %	44,7 %

3. Test runs

3.1 Description of test plan

The testing of the Triptych 6 system was planned co-operatively by the project members. It considers both the methodology of the Triptych approach (Section 2.1) and the special characteristics of Finland (Section 2.3). The current version of the implemented Triptych system offers limited leeway for the inclusion of special country characteristics. Bearing this in mind we aimed to implement a test plan that could tackle the most significant issues without requiring methodological changes. In this chapter the sensitivity tests and their results are described. The test plan in Table 5 below provides an overview of the test runs and the affected parameters.

As indicated in Section 2.1, the Triptych methodology is the most complicated for electricity production and the industrial sector. All other sectors are assumed to converge to a certain per-capita level, or according to an annual percentage pre-set for the view years. Furthermore, as it was not possible to include country-specific values for such emission reduction parameters in the model, the individual testing of these 'other sectors' would make no sense. Consequently, the sector specific test runs were focused on the electricity production and industrial sectors only.

First of all, the impact of the inclusion of national data instead of regional-based data into the model needed to be tested. The national scenarios for GDP, population, the industrial value added index (IVA) and for the electricity demand index were submitted to Ecofys by VATT and VTT to be included in the EVOC tool.

The default population development of Finland in the Triptych 6 system is based on standard IPCC-SRES assumptions for Europe as a whole. This development deviates from the national forecasts of Statistics Finland. Furthermore, according to current insights regarding the development of population in relation to climate change (Carter et al. 2005), it does not seem necessary to distinguish between Finnish demographic scenarios for each of the IPCC-SRES-based main alternatives (A1, A2, B1, B2). As a consequence, one population scenario for Finland would be applied to all scenarios. The differences are summarized in Appendix A.

Similarly to population, an alternative for the default developments of GDP and industrial value added have been provided, based on the work for the revision of the Finnish national climate strategy (MMM 2005, Carter et al. 2005). The differences are summarized in Appendix A.

As indicated in Section 2.3.3, average growth rates for electricity demand and industrial production, applied in the original Triptych approach applied for the EU's internal burden sharing for the First Period of the Kyoto Protocol, resulted in a tight allotment of emission rights for Finland. Consequently, we planned to test how the results would change if national demand-derived scenarios were used.

Secondly, as the parameter set on the reduction stringency of sectors is selected manually, we decided to test how different selections would influence national reduction targets. Three of the most critical sectors for Finland: electricity production, industry and the domestic sector were selected to be tested.

The influence of the base year selection was also one of the major interests, and it was decided to test it by choosing one favourable and one unfavourable year as base years. In the EVOC tool electricity growth is derived by applying electricity demand indexes directly to gross production figures for the latest available statistical year. As the balance between electricity imports and exports in that particular year may have a relatively significant impact on the results, we decided to use the demand figure instead of the gross production value to find out the influence.

The most difficult methodological issue in the Triptych 6 system is the way of handling CHP production, as it is almost impossible to find an unambiguous solution for that. The problem is caused by the lack of definition of heat or steam demand related to CHP production, and by a lack of separation of fuels between electricity and heat production. The methodology is not problematic for most of the countries with a very low current share of CHP in electricity production, because the requirements are similar for all. Instead, the efficiency of electricity production is not described suitably for countries already making notable use of CHP. Consequently, we tried to find out the sensitivity of CHP methodology by implementing some simple tests.

The Triptych approach is one method to be used as part of the Multistage model (see Chapter 2.2). Therefore, we decided to test the impact of using different burden sharing methods in the final stage of the Multistage model (Table 5).

Table 5. Plan for the test runs.

No.	Goal	To do	Change in	Approach	Scenario/ future data set	Country
1	Check impact of Finnish input data (from VTT) compared to EVOC standard data	Change GDP growth rates c.p.	Input data	Triptych + Multistage	Min and max/ 6 SRES + data (growth rates) provided by VTT	Finland
2		Change electricity consumption growth rates c.p.				
3		Change IVA growth rates c.p.				
4		Change population growth rates c.p.				
5		Check combined impact c.p.				
6		Check impact on 3 major sectors (industry, electricity, domestic)				
7	Check impact of different parameter sets on reduction stringency of sectors	Calculate 3 cases: Each with extreme data for one sector (industry, electricity or domestic having high emissions)	Parameter set	Triptych	6 SRES	Global
8	Check impact of another base year/ period than 2001	Change base year --> using one average year (2002), one low-emission and one high-emission year as basis	Methodology	Triptych	6 SRES	Finland
9	Check impact of electricity imports/ exports for Finland	Include imports/ exports		Triptych	6 SRES + data (import/ export) provided by VTT	Finland
10	Check impact of different methodologies to cope with CO_2 eq/ kWh	Look at CO_2 eq/kWh with current methodology		Triptych	6 SRES	Finland, Brazil, China, Netherlands, Germany
11		Use detailed statistics of CHP, at least certain share of CHP		Triptych	6 SRES	
12		Keep CHP out of calculation		Triptych	6 SRES	
13		Calculate with converging CO_2 eq/kWh		Triptych	6 SRES	
14		Reduce CO_2 eq/kWh at same percentage rate		Triptych	6 SRES	
15	Check impact of different reduction methods in the final stage of Multistage	Calculate 3 different reduction methods in the final stage (Triptych, same reduction for each country, reduction based on per-capita emissions)		Multistage	6 SRES	Global

3.2 Results

(Sara Moltmann and Niklas Höhne, Ecofys)

3.2.1 Inclusion of national data for Finland

We tested the impact of the inclusion of national data for Finland on the country's emission reduction obligations under Triptych and Multistage. Therefore, we exchanged the general EVOC growth rates of electricity consumption, industrial value added (IVA) and population. We did not replace national GDP data because this does not have an impact on the final emission reductions in all approaches.

Each of the changed parameters influences exactly one of the major sectors within the Triptych approach: the change of electricity consumption growth rates has an impact on emissions in the electricity sector; the change in IVA growth rates influences emissions in the industry sector; changing population growth rates affects emissions in the domestic sector.

The Finnish and the EVOC data are not completely comparable. The original data is based on the IPCC SRES scenarios, which were developed in the late 1990s and which are "non-intervention" scenarios. They do not include emission-reduction policies. The Finnish data were developed at a later date and assume some national policies and measures.

For a comparison of the national Finland input data with the original EVOC data see Figure 5 below. The Finnish IVA index is considerably higher compared to the EVOC index in 2050, with a difference of +250 to +150 percentage points. The Finnish electricity demand index is higher than the average of the IMAGE data used in EVOC until about 2040. Until 2030 the growth rates can also be higher than those in the A2, B1 and B2 scenarios in EVOC. But on average the growth rates of Finnish electricity demand are lower. In contrast to this, the two population indices stay comparably close. The Finnish index is only slightly higher.

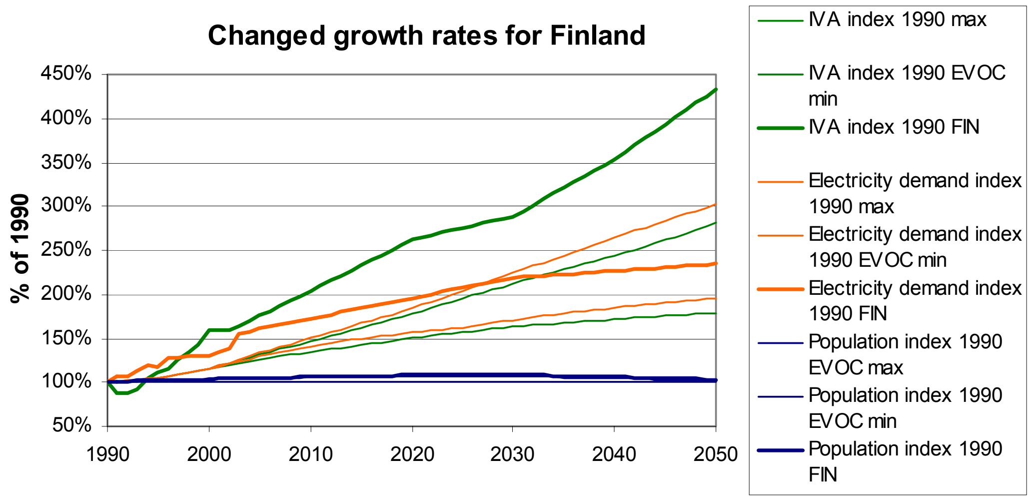


Figure 5. Changed growth rates of national data and EVOC data for Finland from 1990 to 2050. (Finnish electricity growth rates according to Forsström and Lehtilä, 2005, p. 71, app. p. 9, IVA and population growth according to Carter et al., 2005).

The following figures show the impact of the national data for Finland and how they influence total reduction obligations. Higher growth rates lead to less stringent emission reductions of the respective sector, and vice versa. As the total emissions of Finland are small compared to the global total, the changes of these input data for Finland data have no important effect on Annex I or on global emissions.

The ranges in the EVOC data are caused by growth rates from different scenarios and different "normative but scenarios derived" corrections in the different scenarios. In the Finnish data set the growth rates are the same for all scenarios. But the correction of the indices that is part of the method applied by EVOC is also causing ranges here (Figure 6 and Figure 7).

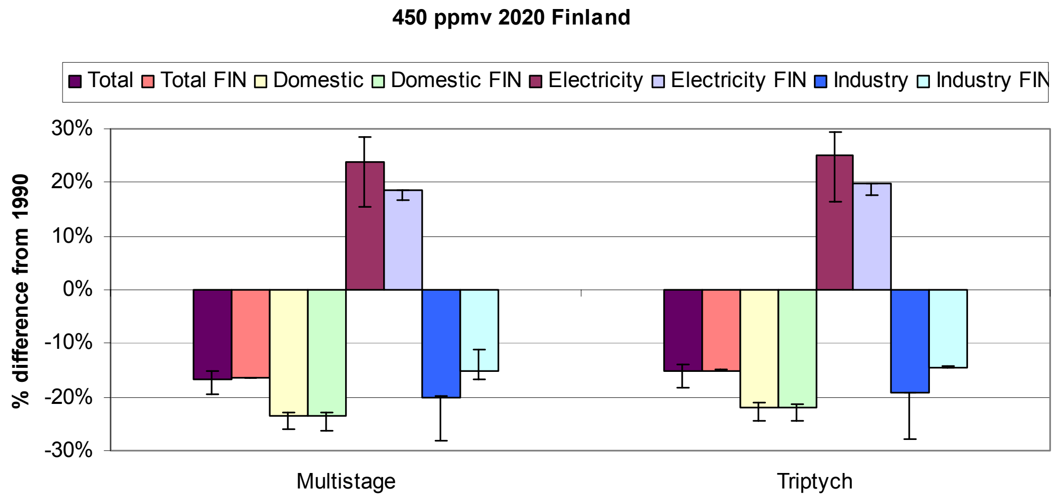


Figure 6. Change in emissions from 1990 to 2020 due to Multistage and Triptych under the 450ppmv scenario: Inclusion of national data for Finland. EVOC data ranges are due to the six SRES scenarios. Sector changes are related to 1990 sector data.

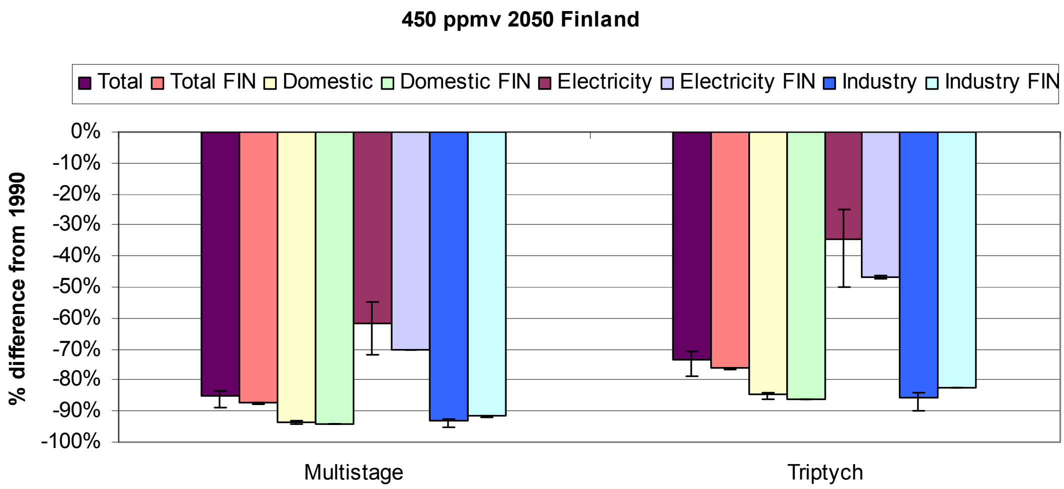


Figure 7. Change in emissions from 1990 to 2050 due to Multistage and Triptych under the 450ppmv scenario: Inclusion of national data for Finland. Ranges are due to the six SRES scenarios. Sector changes are related to 1990 sector data.

Domestic sector

The exchange of population growth rates has a negligible influence on the final emissions of the domestic sector under both the Multistage and Triptych approaches. For 2020 the reductions are about the same. For 2050 reductions become more stringent by 0.5 to 1 percentage point. On total emissions this has an influence of about -0.2 percentage points. We already expected this when checking the model in comparing country-specific GDP and population data for Finland (App. A), and when considering Figure 5. The results of the test runs in Figure 6 and Figure 7 verify this assumption.

Electricity sector

In the electricity sector the changes in emission reductions due to the changes of input data are much more noticeable for both Multistage and Triptych. Generally, the reductions are stricter with the Finnish data set compared to the A1 scenarios in EVOC until 2020 and compared to all SRES scenarios until 2050.

Regarding the original EVOC output for 2020, this means a smaller increase of emissions compared to 1990 of about 5 percentage points for the electricity sector. Because electricity has a share of about one-third of total emissions, this is equivalent to about 1 percentage point of national emissions.

For 2050 the Finnish data set results in a more stringent reduction of about 9 to 12 percentage points for the electricity sector. This is equivalent to about 2 to 3 percentage points of the national total. This comparably high influence on total emissions is caused by the high share of electricity in total emissions, which are around 62% and 55% for EVOC input data and Finland national data respectively.

Industry sector

For the industry sector the trend in emission reductions is inverse compared with the electricity sector. The reductions with the Finland input data are more relaxed than with EVOC data. As assumed, this is caused by the higher growth rates of the Finnish IVA index since 1990.

In 2020 this means a relaxation of 5 percentage points for the industry sector. In 2020 industry has a share of about one-fifth of total emissions. This leads to an influence of 1 percentage point in total emissions.

For 2050 this relaxation of reduction obligations accounts for about 2 to 3 percentage points for the industry sector. Caused by a decreasing share of industry in total emissions (8% to 13%), the influence of this relaxation is about half a percentage point of the total emissions.

Although the difference between the EVOC and Finland national data is comparably high, the final impact on total emissions is lower than that of the electricity sector. This is caused by the lower share industry has in total emissions.

Total national emissions

The change of the whole data set on total national emissions results in insignificantly relaxed reductions in 2020, as the two effects are in the opposite direction and almost cancel each other out. In 2050 the lower electricity growth rates clearly cause higher reduction obligations. The Finland input data increase total emissions reductions by 2 to 3 percentage points.

3.2.2 Change in Triptych parameters

The global reductions of the different sectors in the Triptych approach are very diverse. Therefore, we calculated different Triptych cases in order to see how changes in the parameter set affect the emission reduction obligations of the main sectors and of the national total. The global total emissions are the same for all cases. As one example we chose the 450ppmv development path for 2050, because trends and changes can be seen more clearly compared to 2020. Table 6 shows the changes we made. The basis for this are the calculations made for the Triptych approach (450ppmv, 2050) in the first report (Höhne and Ullrich, 2005).

Table 6. Parameter choices to reach 450 ppmv in 2050 for the Triptych sector sensitivity calculations ("-" indicates no change to the original Triptych calculation).

Sector	Quantity	Triptych original	Domestic relaxed	Electricity relaxed	Industry relaxed	All sectors same reduction for Annex I	All sectors same reduction globally
Electricity	Maximum deviation of total power production at the country level in 2050	45%	-	-	-	-	-
	Maximum deviation of total power production at the global level in 2050	10%	-	-	-	-	-
	Share of renewables and emission-free fossil in 2050	60%	70%	53%	70%	80%	70%
	Share of CHP in 2050	35%	10%	35%	10%	9%	20%
	Reduction of solid fuels in 2050 compared to base year	75%	80%	60%	80%	80%	83%
	Reduction of liquid fuels in 2050 compared to base year	75%	80%	60%	80%	90%	80%
	Total efficiency of CHP	90%	-	-	-	-	-
	Convergence of power generation efficiency of solid fuels in 2050	50%	-	-	-	-	-
	Convergence of power generation efficiency of liquids fuels in 2050	50%	-	-	-	-	-
	Convergence of power generation efficiency of gas in 2050	65%	-	-	-	-	-
Industry	Maximum deviation of total industrial production at the country level in 2050	45%	-	-	-	-	-
	Maximum deviation of total industrial production at the global level in 2050	10%	-	-	-	-	-
	Convergence of Energy Efficiency Indicator in 2049	0.4	0.4	0.4	0.9	0.44	0.45
	Structural change factor in 2049	0.3	0.3	0.3	0.3	0.4	0.4
Domestic sector	Domestic convergence level - per-capita emissions in t CO_2/cap/yr in 2050	0.7	0.85	0.5	0.5	0.92	0.76
Fossil fuel production	Fossil fuel emission level – % total emissions below base year in 2050	90%	-	-	-	-	-
Agriculture	Reduction below reference scenario emissions in 2050 – low GDP/cap	50%	-	-	-	-	-
	Reduction below reference scenario emissions in 2050 – high GDP/cap	70%	-	-	-	-	-
Waste	Waste convergence level – per-capita emissions	0	-	-	-	-	-

In each of the following three cases in Figure 8 and Figure 9, two of the major sectors, domestic, electricity and industry, had to reduce a higher share of emissions than in the base calculations, so that the third sector could reduce less in order to reach the same global emission level. The configurations of the high-reducing sectors were approximately those we also assumed in the last report for a global 400ppmv path. Only the configurations for high reduction in industry we kept constant, because the reductions were comparably stringent already for 450ppmv. Changed parameters are the convergence level of per-capita emissions (domestic), the fuel mix (electricity), the energy efficiency index and the structural change index (industry). The parameter configuration of the sectors waste, fossil fuel production and agriculture we kept constant with the same settings as in the calculations for the last report to reach the global 450ppmv CO_2 level.

The countries' sectoral shares of emissions and the sector-based allocation method of the Triptych approach lead to a slight shift compared to the original Triptych outcome. A general trend can be seen for most of the tested regions (see Figure 8 and Figure 9). With relaxed reductions for the domestic or the industry sector the total reduction obligations increase for the group of Annex I countries and decrease for the group of Non-Annex I countries. In the case of relaxed reductions for electricity the total reduction obligations are slightly lower for most Annex I countries and slightly higher for most Non-Annex I countries but generally closer to the original Triptych outcome. Due to the diverse structures of the economies in Non-Annex I countries, the deviations among countries are higher in this group.

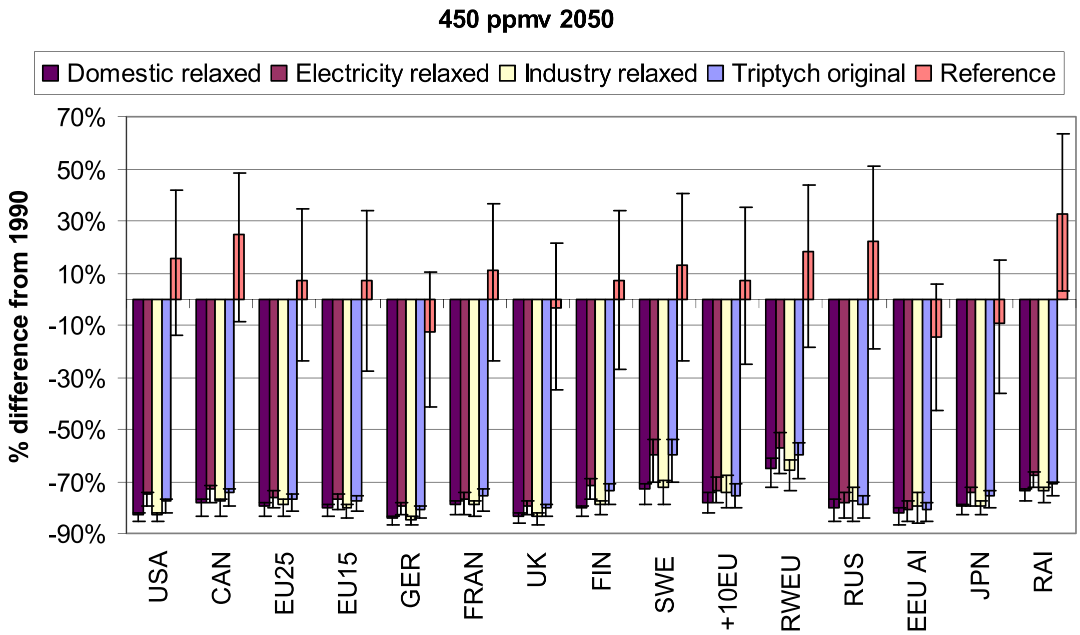


Figure 8. Sector sensitivity analysis for Annex I regions: Change in emissions from 1990 to 2050 under the 450ppmv scenario. Ranges are due to the six SRES scenarios.

Figure 8 shows the difference in emissions reductions between France and Sweden (see also Figure 20 and Figure 22). This is remarkable because these two countries are assumed to have comparable national conditions regarding the share of emission-free electricity output.

The variation between France and Sweden in Triptych can be explained by several factors. One is the different development of the structures of the electricity sectors. This is a result of the implementation we chose for the Triptych approach in EVOC. France has higher reductions in 2050 compared to Sweden, caused by a higher absolute amount of emission-free nuclear which stays constant and less negative gas correction that reduces the share of renewable energy. That Sweden has to comply with less stringent national reductions is even supported because the chosen Triptych configurations favour the electricity sector (see as well Figure 10 and Figure 11). As a consequence, in 2050 Sweden has a higher share of electricity in total emissions (64%) compared to France (40%), which has a high influence on the national total reductions.

Furthermore, higher per-capita emissions in the French domestic sector may also have an effect. As already mentioned in the first report (Höhne and Ullrich, 2005), the Kyoto targets also influence the countries' developments for several years. With +4% emissions compared to 1990, Sweden finds more relaxed preconditions than France (0%).

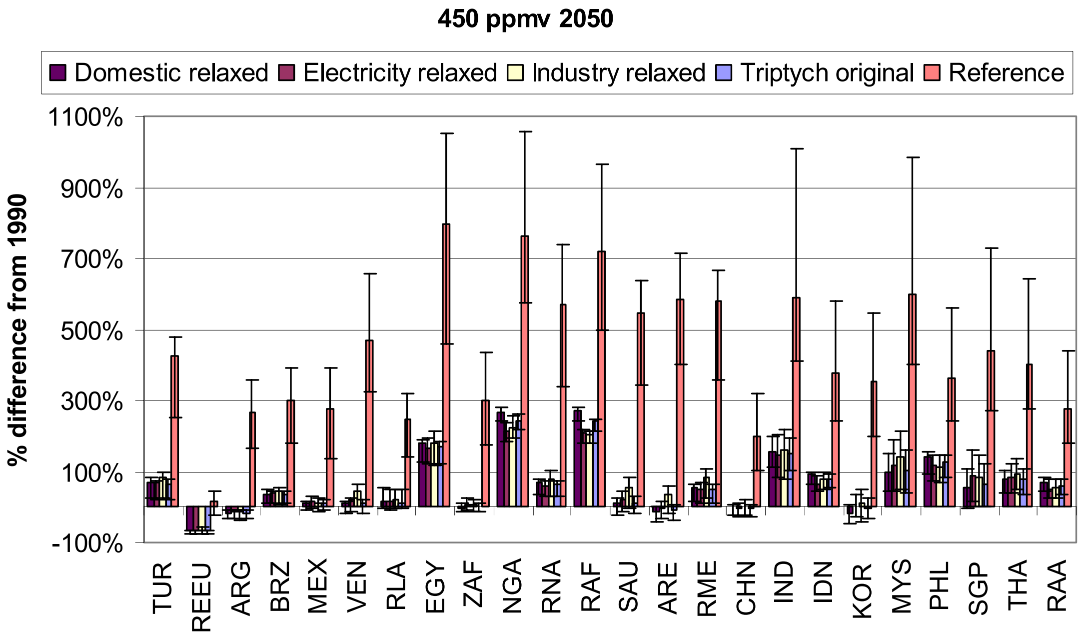


Figure 9. Sector sensitivity analysis for Non-Annex I regions: Change in emissions from 1990 to 2050 under the 450ppmv scenario. Ranges are due to the six SRES scenarios.

Two additional cases are shown in Figure 10 to Figure 12 below for the world total, the group of Annex I countries and Finland. 'Same reduction of all sectors globally' means that on the global level all sectors have to reduce about the same percentage rate compared to 1990. 'Same reduction for Annex I countries' means that sector reduction should be about the same for the whole group of Annex I only.

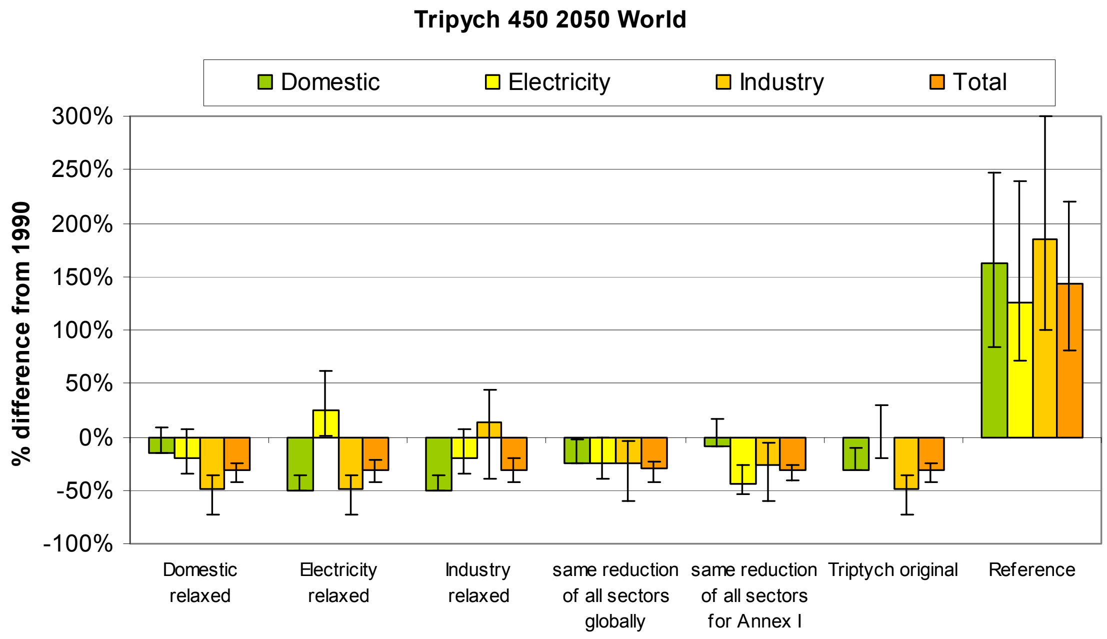


Figure 10. Sector sensitivity analysis for the global total: Change in global emissions from 1990 to 2050 under the 450ppmv scenario. Ranges are due to the six SRES scenarios.

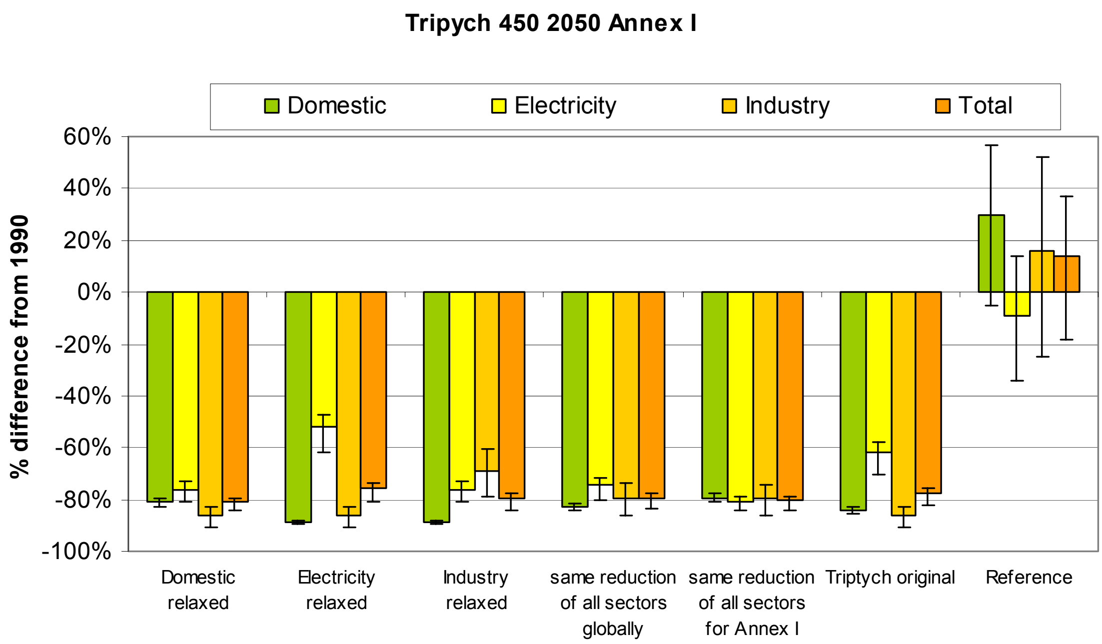


Figure 11. Sector sensitivity analysis for Annex I: Change in emissions from 1990 to 2050 under the 450ppmv scenario. Ranges are due to the six SRES scenarios.

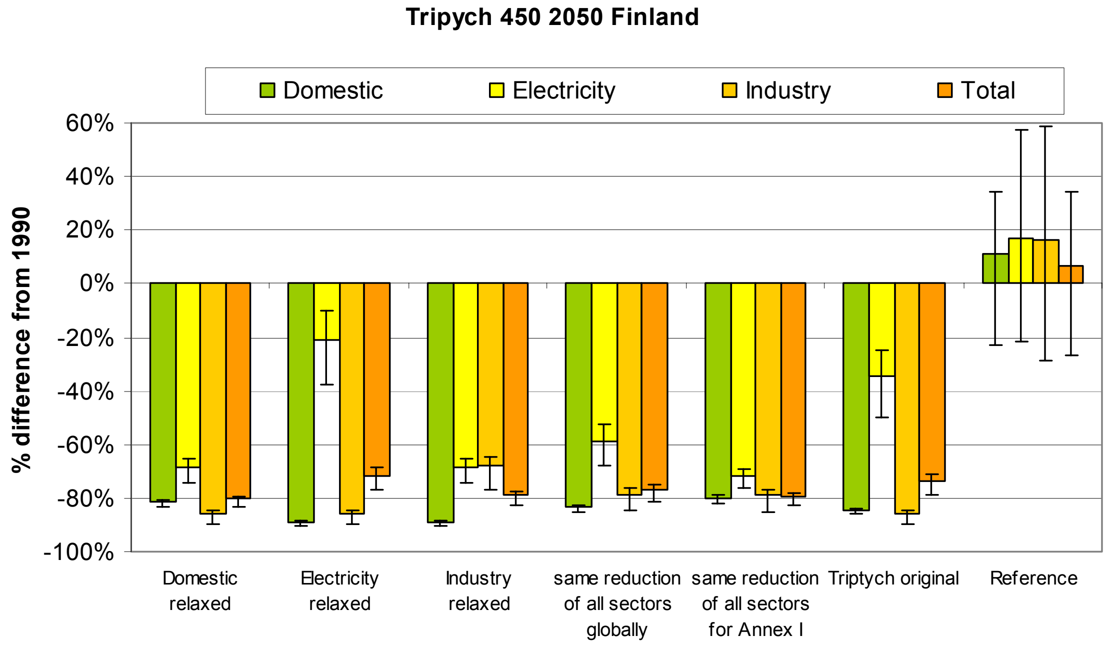


Figure 12. Sector sensitivity analysis for Finland: Change in global emissions from 1990 to 2050 under the 450ppmv scenario. Ranges are due to the six SRES scenarios.

The results, especially for Finland, are similar to those of other Annex I countries both in 2020 and 2050 (see Figure 8 and Figure 12). The increased emissions in one sector have to be compensated for in the other sectors. Compared to the original Triptych calculations, the reduction commitments are more stringent in the cases of relaxed reductions for the domestic and the industry sector.

The emissions in the Finnish electricity sector do not have to be reduced proportional to other sectors or the average and the other Annex I countries. This could be due to Finland's comparably low emissions per kWh in the electricity sector in 1990 (see also section 3.2.5).

In the case of relaxed reduction obligations in the electricity sector, the overall reduction commitment in 2050 compared to the original Triptych calculation decreases slightly, which reflects the high share of electricity in national emissions (Figure 12). This high contribution can also clearly be seen in all other cases which lead to higher reduction obligations due to a more stringent reduction of the electricity sector.

For 2020 the differences among the five cases are similar but not as clear as in 2050. The Finnish reductions lie at around -15% compared to 1990 (Triptych 6 original). 'Electricity relaxed' leads to slightly relaxed total reductions of about +1 percentage point. The same reductions for all sectors in Annex I lead to more stringent reductions of -2.5 percentage points. 'Industry relaxed', and 'same reduction globally' lead to more stringent reductions of +1.5 percentage points. 'Domestic relaxed' results in -3 percentage points.

3.2.3 Base year analysis

In this analysis we changed the base year of the Triptych calculations to see whether this has a big impact on the results. Strictly speaking, two base years exist in the Triptych approach as it is implemented in EVOC apart from the reference year 1990. For this project these are 2001 and 2010. 2001 is the latest year for which historical data are used. 2010 is the year in which the Triptych methodology is started. The shares in the fuel mix stay the same from the base year 2001 until the starting year of Triptych, 2010 in this case.

The base year we changed was only the first one, 2001. This cannot be calculated in the EVOC tool directly, but was done separately in MS Excel. Due to reasons of data availability within the EVOC tool, we chose one high-emission and one low-emission year for Finland between 1990 and 2001 (see Table 7). We selected 1992 as the year with low emissions, having a comparably high share of renewable and nuclear energy in the fuel mix. 1996 as a high-emission year has a comparably high share of energy from coal and a low share of renewable energy.

Table 7. Emissions in CO_2 equivalents for Finland.

Mt	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
EVOC CO_2 eq. emissions in the electricity sector	18.91	19.54	17.92	20.41	25.18	22.99	28.19	25.31	22.01	21.64	20.17	27.30

The difference between the low and the high-emission year in 2020 makes up for about -12 and +27 percentage points of total emissions; in 2050 for about -2 and +7 percentage points. It has a comparably high influence. Under the Triptych approach electricity has a share of about 60% of total national emissions in 2050. Projected onto total emissions, this is a difference of about -3 and +6 percentage points of the total 2020 emission reductions with the base year 2001, and -1 and +2 percentage points of the 2050 reductions (Figure 13). However, the results below show that the base year 2001 leads to comparably average reduction obligations.

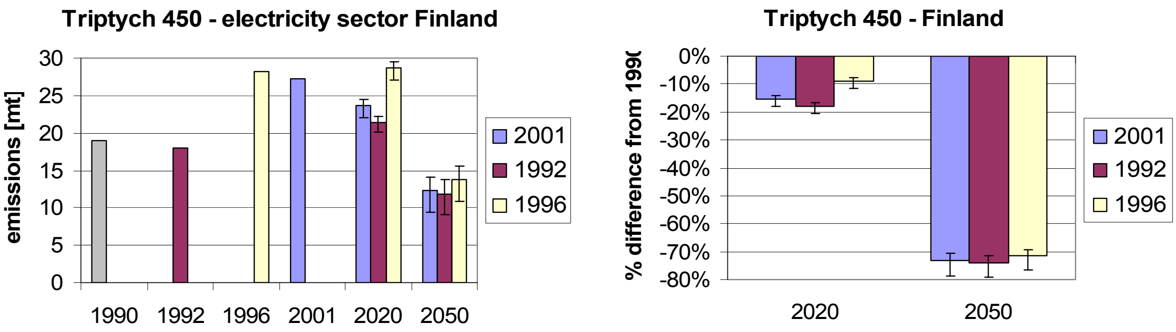


Figure 13. Base year sensitivity analysis: Change in emissions in the electricity sector from 1990 to 2050 under the 450ppmv scenario for Finland. Electricity sector only (left), national total (right). Ranges are due to the use of the six SRES scenarios.

3.2.4 Including electricity imports

Originally, the EVOC tool did not consider imports or exports of electricity. As a consequence, only the total electricity output within one country is reflected when calculating national emissions. To see whether the inclusion of net imports makes a difference for the final emissions under the Triptych approach in EVOC, we included these data for Finland (see Table 8). As with the calculations for different base years, this is not possible within the EVOC tool but was done separately.

Table 8. Net imports for Finland.

TWh	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2010**	**2020**	**2030**	**2040**	**2050**
Net imports	10.74	7.18	8.23	7.54	6.08	8.41	3.66	7.65	9.31	11.12	11.88	*11.90*	8.00	5.00	0.00	0.00	0.00
Gross consumption	65.69	65.54	66.37	69.01	72.04	71.96	73.19	77.17	79.86	81.04	82.34	84.86					

(Source: Statistics Finland (2003). 2001 value in italics: linear interpolation)

Figure 14 shows the emissions for the two cases excluding and including net imports for Finland. The emissions excluding net imports consider those electricity shares the EVOC tool calculates. The emissions including net imports additionally contain those emissions resulting from the imports mentioned in Table 8.

As Figure 14 demonstrates, the inclusion of net imports in the calculations has an effect of about +4 percentage points on the final reduction level in 2020. Until 2050 no major influence exists any more, because for this year no imports are assumed. But the inclusion of net imports increases emission reductions in 2050 from -35 to -42 percentage points compared to 1990 electricity emissions. This difference of about -7 percentage points is equivalent to about -1 percentage point of the national total.

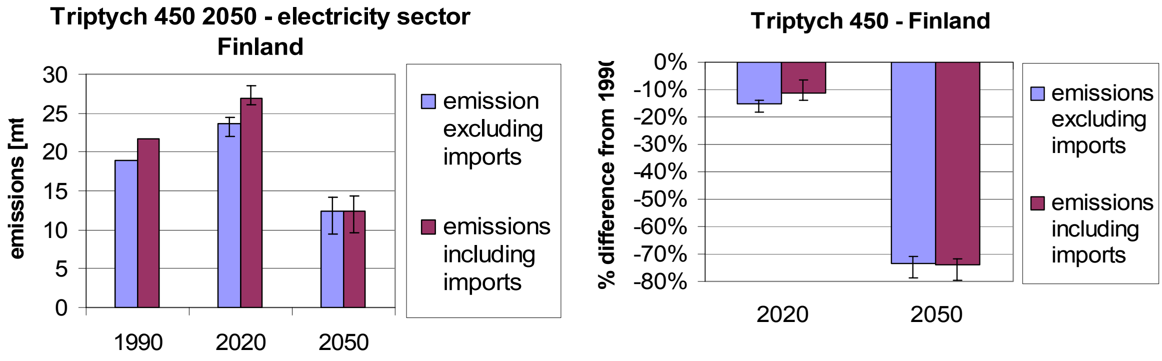


Figure 14. Including net imports added to the regular electricity output: Change in emissions in the electricity sector (left) and national total (right) from 1990 to 2050 under the 450ppmv scenario for Finland. Ranges are due to the use of the six SRES scenarios.

A second possibility to include net emissions is to take Finland's gross consumption of electricity to be equal to the national electricity output until 2001. With these figures and the corrected electricity demand index for 1990, the emission allowances for the following years can be calculated.

While in Figure 14 no imports are assumed, from 2030 on the imports until 2001 are extrapolated until 2050 in Figure 15. This results in less stringent emission reductions for the Finnish electricity sector of about +4 percentage points of total national emissions in 2020 and about +2 percentage points in 2050.

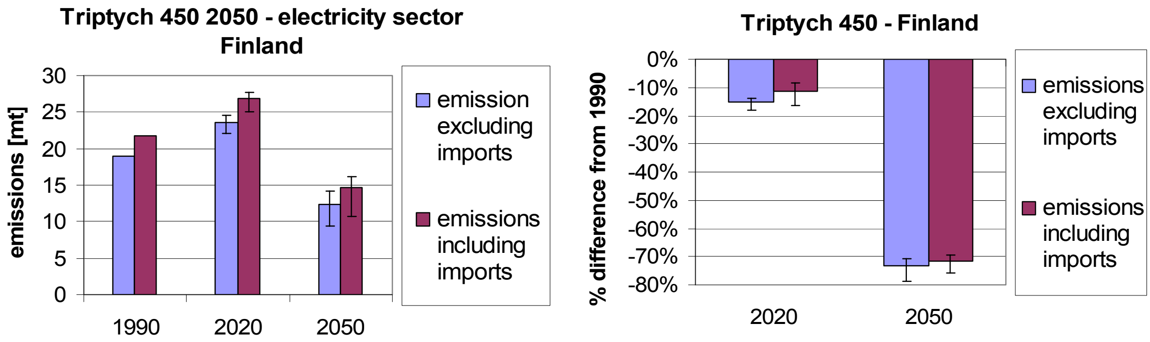


Figure 15. Including net imports until 2001 and applying regular electricity demand index: Change in emissions in the electricity sector (left) and national total (right) from 1990 to 2050 under the 450ppmv scenario for Finland. Ranges are due to the use of the six SRES scenarios.

3.2.5 Different methodologies for the electricity sector in Triptych

We compared different Triptych methodologies for the electricity sectors of Brazil, China, Finland, Germany, the Netherlands and the world average. We considered five different cases:

- The original methodology as in EVOC, adding a specific share of additional CHP after 2010
- The original methodology without the requirement for CHP (no additional CHP in the future)
- The original methodology using CHP statistics as a starting point and adding the remaining share of CHP
- Converging CO_2 eq./kWh
- Equal reduction of CO_2 eq./kWh.

The figures below show the tested reduction methods for the 450ppmv pathway until 2050 under the Triptych approach. Emissions per kWh for the different countries were not very homogeneous in 1990. They lie between 50g and 960g of CO_2 eq. per kWh.

Figure 16 shows the original EVOC calculations. On the left hand side CHP is included as usual, which means a share of 35% in 2050. This leads to a convergence of emissions of between 90 g and 118 g of CO_2 eq. per kWh for the five countries. This is equivalent to an increase of emissions of 72% (Brazil) and a reduction for all other countries of -74% to -88% compared to 1990.

On the right hand side the share of additional CHP is assumed to be 0 in 2050. For Brazil, China and the Netherlands emissions per kWh increase (123g to 141g CO_2 eq. per kWh). Germany and Finland have lower emissions (77g to 96g CO_2 eq. per kWh) without CHP than in the base case. In countries with higher emissions the missing share of CHP is mainly substituted with gas. In the countries with lower emissions the decrease of emissions is caused by the ‘negative gas correction’ of the original methodology. The correction is used when the configurations cause the remaining share for gas to become negative because the other fuels together make up more than 100%. The gas correction is subtracted from the shares of CHP and renewable. When the share of CHP stays at 0 this gas correction might become very small or disappear completely. Therefore, renewable also gets a higher share in the total fuel mix. As a consequence emissions per kWh decrease.

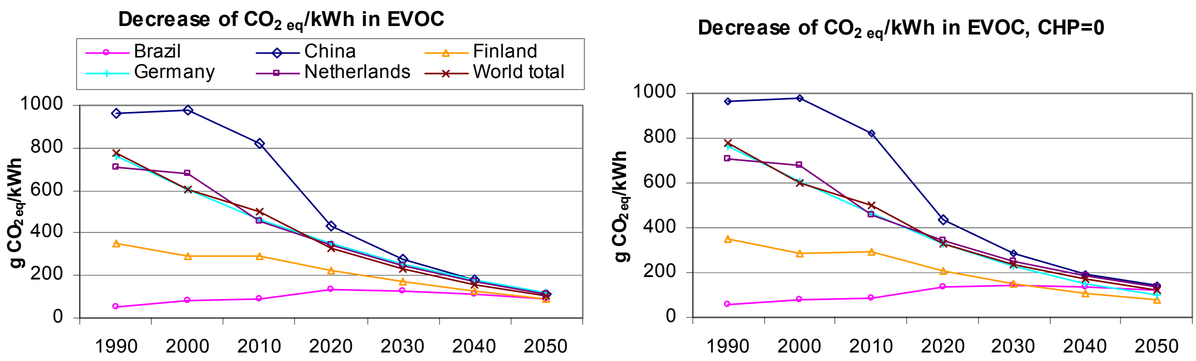


Figure 16. Development of CO_2 eq. per kWh: Share of CHP 35% and 0% in 2050 under the 450ppmv scenario for Brazil, China, Finland, Germany and the Netherlands.

For the next case we started from 2001 with detailed CHP statistics (see in Figure 17). In the previous cases it was assumed the CHP share is zero in 2001. The parameter that was 35% in the previous calculations was now changed to the value given in Table 9, where we subtracted the actual shares of CHP in 2001 from the original 35%. According to this method the results for China and Germany are the same as the normal EVOC case, with CHP=35%. The results for Finland and the Netherlands are the same as the calculation with no CHP until 2050. Only the share of CHP for Brazil decreases compared to the base case. Since the calculations for Brazil include no gas correction, the 2.2% less CHP is replaced with gas. This results in slightly higher emissions. The range of emissions in 2050 then lies between 90g and 112g CO_2 eq. per kWh.

Table 9. CHP shares of total electricity output (Source: IEA 2003).

%	National share of CHP in 2001	EVOC share of CHP in 2050
Brazil	2.20%	32.80%
China	0.00%	35.00%
Finland	42.30%	0.00%
Germany	0.00%	35.00%
Netherlands	100.00%	0.00%

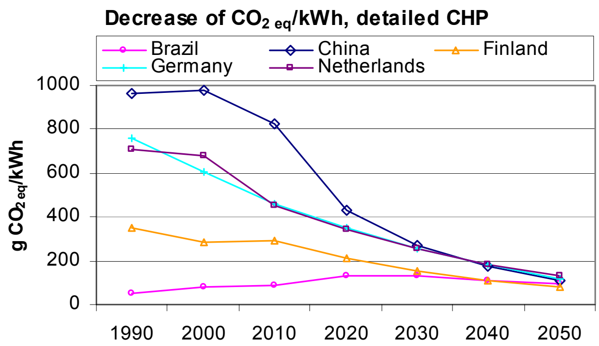


Figure 17. Development of CO_2 eq. per kWh: Detailed statistics of CHP in 2001 under the 450ppmv scenario for Brazil, China, Finland, Germany and the Netherlands.

Figure 18 (right) shows a linear decrease of CO_2 eq. per kWh between 2010 and 2050. On the left hand side we calculated a linear convergence for all countries to the global level of 104g CO_2 eq. per kWh. This reduction level is the same as the global average in the EVOC base case.

On the right hand side of Figure 18 all countries decrease emissions per kWh by 79.4% from 2010 to 2050. This value is the global reduction of CO_2 eq. per kWh which is calculated by EVOC to reach the 450ppmv development path. The implementation of this method also requires low-emission countries like Brazil to reduce emissions after 2010. The convergence in 2050 is not as clear as with the other four methods. For 2050 the range of the five considered countries lies between 18g (Brazil) and 169g CO_2 eq. per kWh (China).

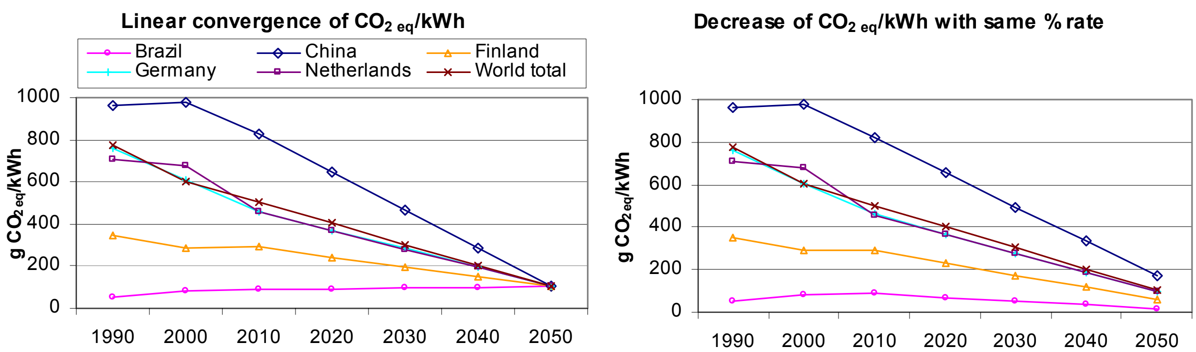


Figure 18. Development of CO_2 eq. per kWh: Linear convergence and decrease with the same % rate under the 450ppmv scenario for Brazil, China, Finland, Germany and the Netherlands.

In Figure 19 we compared the implications of the above-mentioned calculation methods for Finland in 2050. With -70% of 1990 emissions per kWh, only the linear convergence leads to less stringent reductions compared to the -74.2% in the EVOC base case. All other reduction methods result in more stringent emission reductions of about -4 to -9 percentage points.

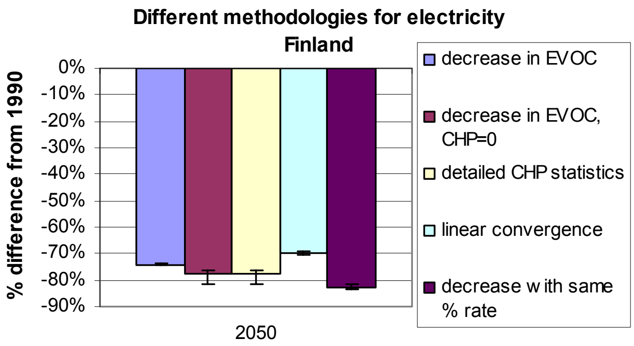


Figure 19. Reduction of CO_2 eq. per kWh in 2050: Comparison of all methodologies under the 450ppmv scenario for Finland. Ranges are due to the six SRES scenarios.

For 2020 the emissions per kWh in the EVOC base case decrease about -31% compared to 1990. Leaving out CHP and the inclusion of detailed CHP statistics both lead to stricter reductions of about -4 percentage points. Linear convergence leads to less stringent reductions of about +6 percentage points, decreasing at the same percentage rate to about +3 percentage points.

3.2.6 Different reduction methods in the final stage of Multistage

In the Multistage model the countries in the final stage have the highest reduction obligations. In the original report we used the Triptych approach to distribute the necessary emissions reductions among these countries. Now, we tested the impact of two other reduction mechanisms: reduction on country basis and reduction on group basis. Reduction on country basis means that every country in the last stage has to reduce total emissions at the same percentage rate. Reduction on a group basis means that the whole group of countries in the final stage has to reduce at a certain percentage rate. Reduction rates of the single countries differ from the overall group reduction depending on their per-capita emissions relative to the groups average per-capita emissions. Countries with higher per-capita emissions reduce more compared to countries with lower per-capita emissions.

The parameters are set as follows: To reach the 450ppmv development path until 2020 the group or country reduction is 1.7% per year. To stay on this path until 2050 the group or country reduction is 2.6% per year. The configurations of the Triptych approach in the last stage correspond to those in the first report (Höhne and Ullrich, 2005). Countries in the last stage stop reducing emissions once their emissions per capita reach 1.5 tCO_2 eq. Figure 20 to Figure 23 show the results of these sensitivity calculations.

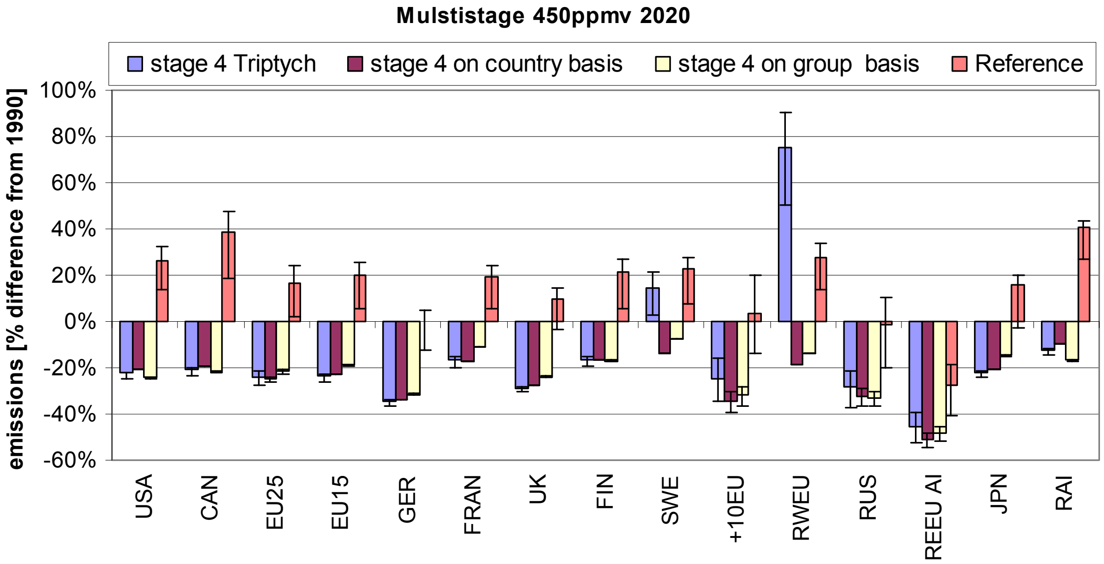


Figure 20. Impact of different emissions reduction methods in the last stage of Multistage for Annex I countries in 2020. Ranges are due to the six SRES scenarios.

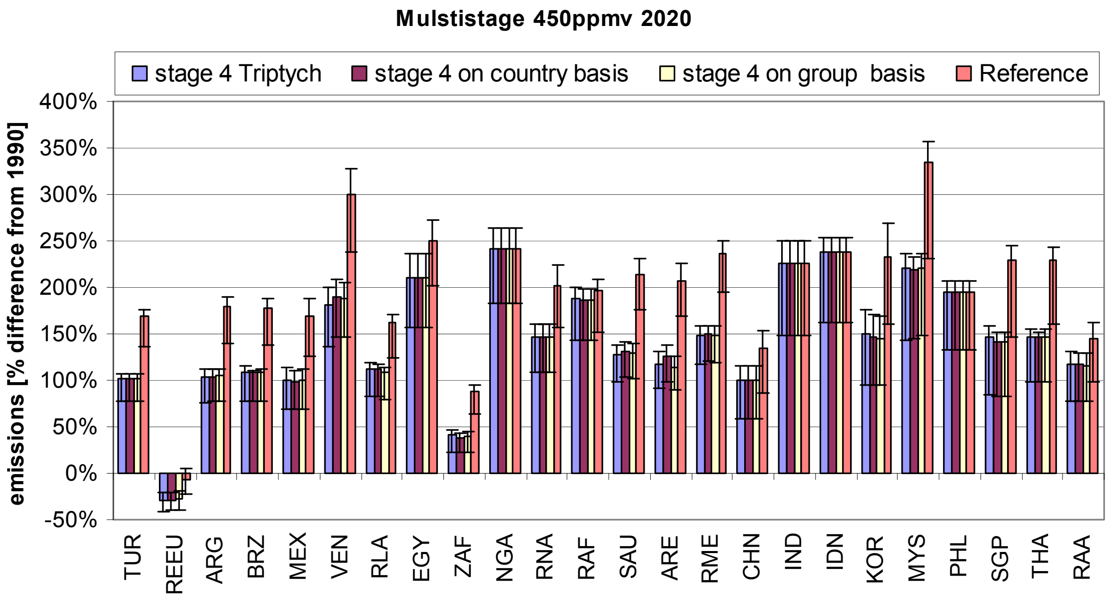


Figure 21. Impact of different emissions reduction methods in the last stage of Multistage for Non-Annex I countries in 2020. Ranges are due to the six SRES scenarios.

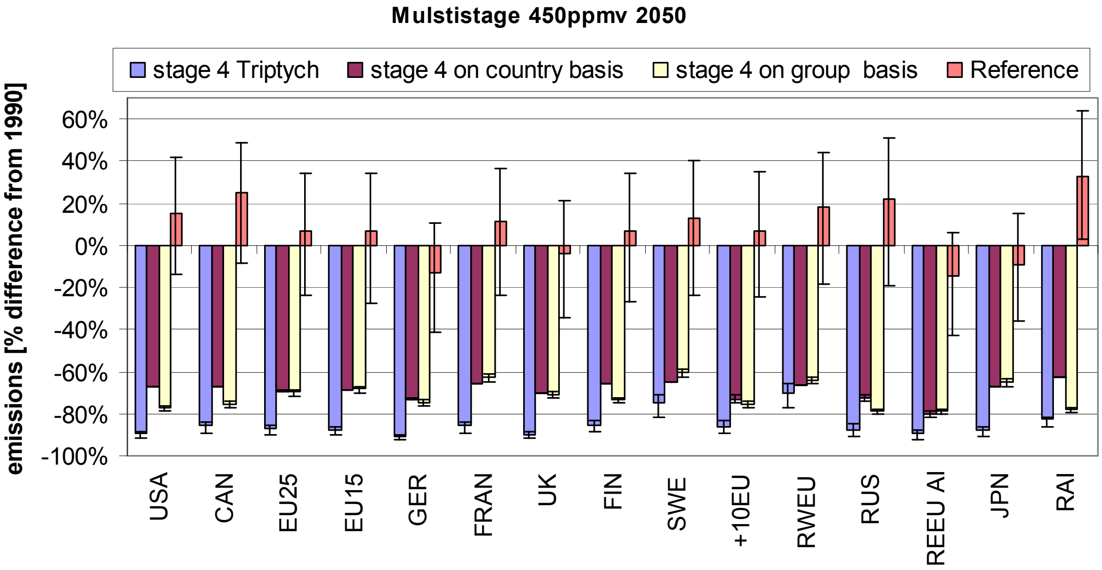


Figure 22. Impact of different emissions reduction methods in the last stage of Multistage for Annex I countries in 2050. Ranges are due to the six SRES scenarios.

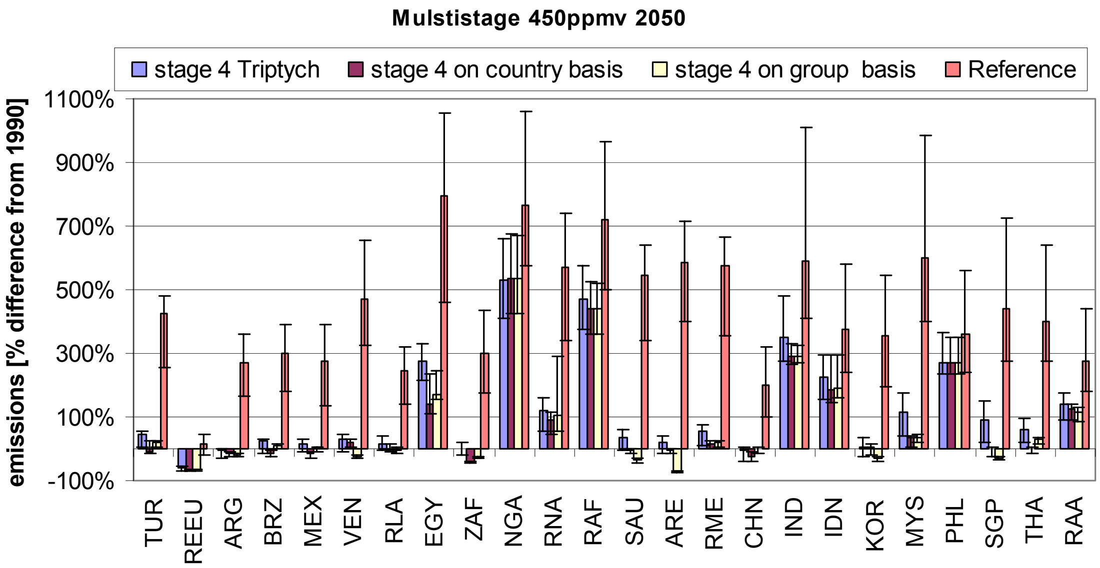


Figure 23. Impact of different emissions reduction methods in the last stage of Multistage for Non-Annex I countries in 2050. Ranges are due to the six SRES scenarios.

In 2020 the reduction obligations under the three different reduction options in the final stage are comparably close. But a general trend can already be seen. Countries with high per-capita emissions (> about 11 tons CO_2 eq. per capita in 2010) have to reduce a higher share on the group basis than on the country basis. For low-emission countries this trend is inverted.

In 2050 the Triptych approach demands more stringent reductions from the Annex I countries than reductions on the country or on the group basis. This is because generally higher growth in industrial and electricity production is assumed for Non-Annex I compared to Annex I countries. Also Non-Annex I countries with high per-capita emissions, such as Argentina or Saudi Arabia, have to reduce later in the cases using the Triptych approach. Additionally, the trend already visible in 2020 becomes more distinct.

3.2.7 Comparison of all calculations

The sensitivity analyses we calculated have different impacts on the total national emissions reductions of Finland (see Figure 24 to Figure 27). The most left-hand bars for Triptych and Multistage show the reductions according to the original calculations.

For 2020 the original Triptych 6 system requires reductions of -15%; Multistage of about -17%. Until 2020 we see for Triptych that many calculations lie within the range that is due to the inclusion of all six SRES scenarios (Figure 24). Only the high-emission base year 1996, the inclusion of imports, and relaxed conditions for the domestic sector require less stringent reductions of up to +5 percentage points. The case of no additional CHP requires more stringent reductions of about -1 percentage point.

For the Multistage sensitivity in 2020 (Figure 25), again the Finnish data set results in similar reductions for Finland in comparison with the original calculations with EVOC growth rates of around -17%. Also the different reduction methodologies for the last stage lead to very similar results.

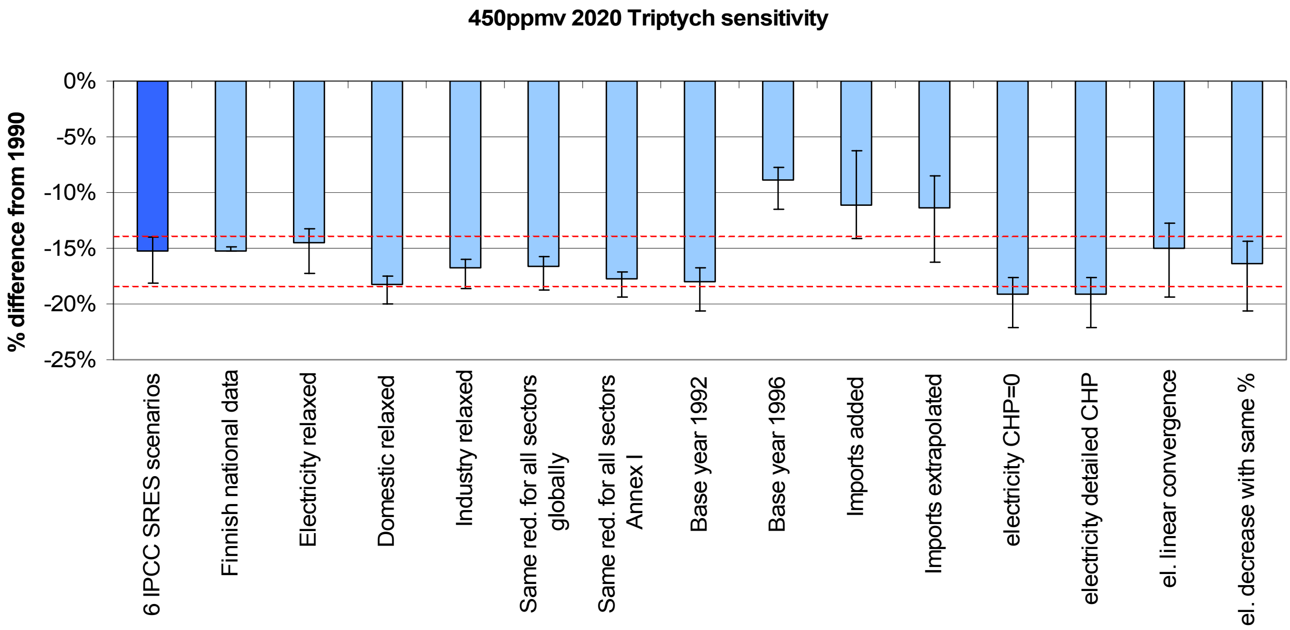
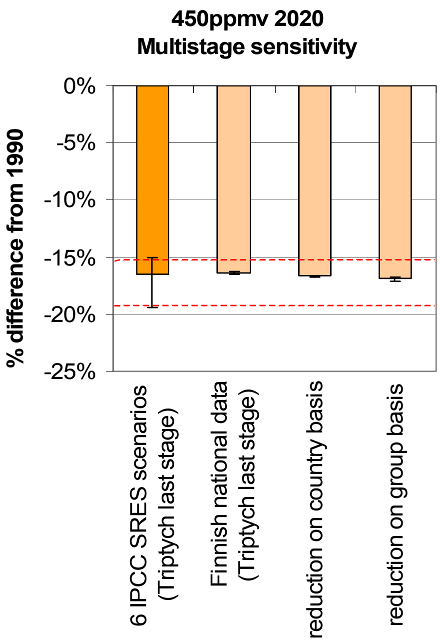


Figure 24. Impact of sensitivity analyses on Finnish emissions reductions for the 450ppmv development path until 2020 for the Triptych approach. Ranges are due to the six SRES scenarios. These ranges are approximations for the different electricity methodologies.



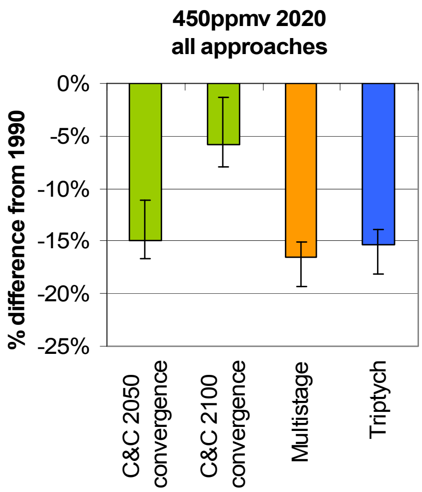


Figure 25. Impact of sensitivity analyses on Finnish emissions reductions for the 450ppmv development path until 2020 for the Multistage approach (left) in comparison with the original results of all approaches (right). Ranges are due to the six SRES scenarios.

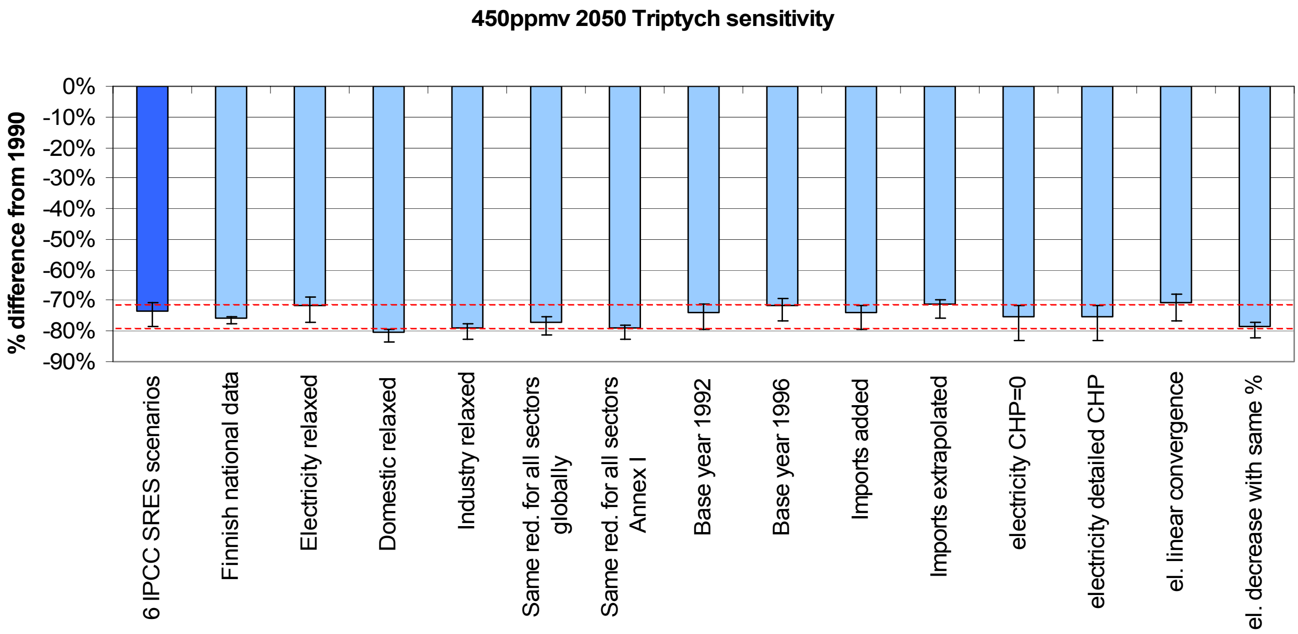


Figure 26. Impact of sensitivity analyses on Finnish emissions reductions for the 450ppmv development path until 2050 for the Triptych approach. Ranges are due to the six SRES scenarios. These ranges are approximations for the different electricity methodologies.

For 2050, the Triptych approach requires reductions of -73% and Multistage of about -85% compared to 1990. For Triptych we see that most of the calculations lie within the range of all six SRES scenarios (Figure 26). Only some configurations of the sector sensitivity in Triptych require more stringent reductions. These are the cases of relaxed reduction conditions for the domestic and industry sector, as well as the same reductions for all sectors for Annex I countries. The maximum deviation from the range amounts to 2 percentage points.

For the original Multistage, the reductions in 2050 are much higher than for Triptych alone (Figure 27). As already mentioned in the first report (Höhne and Ullrich, 2005) this is because the group of countries that reduce emissions is smaller in the last stage of Multistage than in the pure application of Triptych, which requires stronger efforts. For the Multistage sensitivity, again the Finnish data set results in similar reductions for Finland compared to the original calculations. The change of reduction approach in the final stage leads to less stringent reductions which are closer to the results of Triptych and the Contraction and Convergence until 2100.

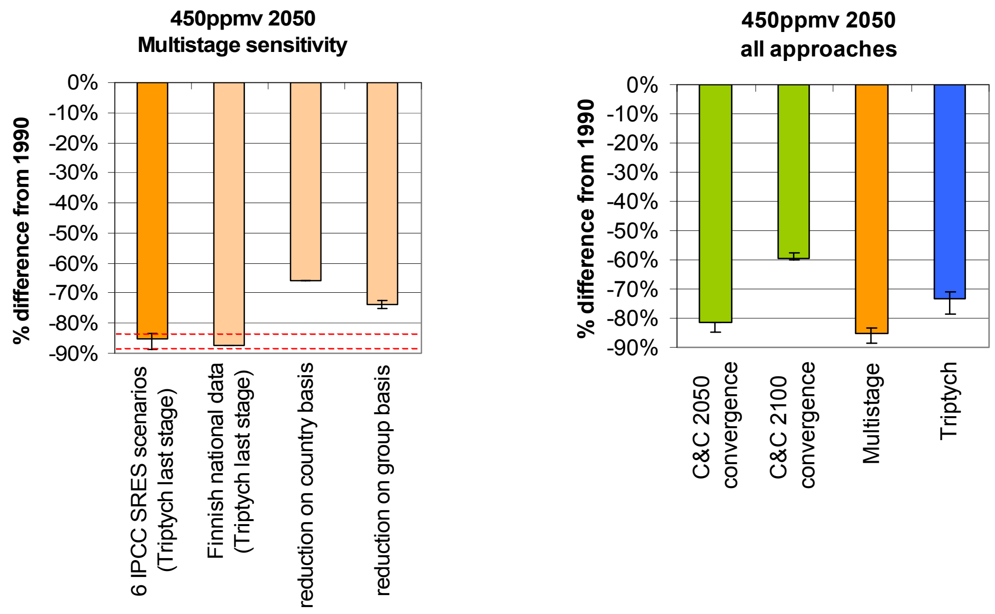


Figure 27. Impact of sensitivity analyses on Finnish emissions reductions for the 450ppmv development path until 2050 for the Multistage approach (left) in comparison with the original results of all approaches (right). Ranges are due to the six SRES scenarios.

In 2020 the reductions for Finland lie at around -9% to -19% compared to 1990 for Triptych and Multistage. In 2050 the reductions lie at around -70% to -80% for Triptych and Multistage, reducing on the group or country basis in the last stage. For Multistage applying Triptych in the final stage, the reduction effort lies at about -85% to -87%. These results are nearly independent of which parameters we change.

3.3 Main lessons of the test runs

(By Sara Moltmann and Niklas Höhne, Ecofys)

This report presents the results of sensitivity analyses of the impact of different options for future international climate policy post 2012 for Finland. After checking the EVOC model itself, we completed sensitivity calculations with changes in parameters and methodology as well as the inclusion of national data for Finland.

The underlying data we use in EVOC match comparably well with the original SRES data. Some inconsistencies occur regarding the electricity-GDP elasticity, but these already occur in the original SRES data as calculated with the IMAGE model.

We found and corrected a mistake concerning the calculation of electricity output and resulting emissions in the Triptych approach. After correcting this mistake the outcomes of the calculations in the first report are not exactly the same. The difference in 2020 is less than 1 percentage point for Finland and 5 percentage points on the global level. In 2050 it is 5 percentage points for Finland and one percentage point globally.

The replacement of regionally derived growth rates with Finnish national growth rates in the Triptych approach leads to no change until 2020 and to stricter emission reduction obligations compared to the original values until 2050. When we include national data for Industrial Value Added (IVA), reductions for the industry sector become less stringent than with the original data. The Finnish electricity demand figures lead to stricter reduction obligations after 2020, which are dominant due to the strong position of the electricity sector. The change of country-specific GDP and population data for Finland does not make a difference in emission reduction obligations.

To test the impact of the parameter choices in the Triptych approach, we calculated five different cases, all leading to the same global emission level: relaxed emission reductions for one of the main sectors (industry, electricity and domestic), as well as similar reductions for all sectors at the global and Annex I level. A general trend can be seen for most of the tested regions. The countries' sectoral shares of emissions and the sector-based allocation method of the Triptych approach lead to a slight shift compared to the original Triptych 6 outcome. With relaxed reductions for the domestic or the industry sector, the total reduction obligations increase for the group of Annex I countries and decrease for the group of Non-Annex I countries. This trend is inverse and closer to the original Triptych 6 outcome for relaxed reductions for the electricity sector.

For Finland the differences among the five cases are similar in 2020 and 2050 but not as clear in 2020. The reductions are more stringent compared to the original Triptych 6 calculations in the case of relaxed reduction obligations for the domestic or the industry sector. In the case of less stringent reduction obligations in the electricity sector, the overall reduction commitment compared to the original Triptych 6 calculation stays nearly the same, which reflects the high share of electricity in national emissions. Due to this the reductions in the Finnish electricity sector also stay below the obligations of the domestic and industry sector for equal reductions of all sectors on a global or Annex I level.

We also considered different base years and the inclusion of electricity imports. As a default we used 2001 as a base year for electricity demand, which seems to be a comparably average base year for Finland. When including imports both tested possibilities lead to a slight relaxation of reductions in 2020. When we add Finnish electricity imports to the electricity demand calculated by EVOC the emission reduction compared to 1990 increases but the absolute emission level in 2050 does not change considerably. Taking the gross electricity consumption of 2001 instead and applying the EVOC growth rates until 2050 results in less stringent reduction obligations.

We compared different methodologies to decrease the amount of CO_2 eq. per kWh for Brazil, China, Finland, Germany, the Netherlands and the world average. In the EVOC base case emissions converge at between 90g and 118g of CO_2 eq. per kWh in 2050 for the five countries. Without additional CHP after 2001 the convergence is not as clear as in the base case. When we include detailed CHP shares in 2001 the outcome for China and Germany is similar to the EVOC base case (CHP=35% in 2050), and for Finland and the Netherlands it is similar to the calculation with no CHP until 2050. The resulting emissions for Brazil (32.8% CHP in 2050) lie below the base case. Linear convergence of emissions leads to results in 2050 comparable with the base case. Emissions decreasing at the same percentage rate for all countries also lead to reductions for low-emission countries.

Compared to the base case for Finland, linear convergence and the decrease of emissions at the same percentage rate for all countries lead to less stringent reductions in 2020 (-25% to -28% of 1990 CO_2 eq. per kWh). The most stringent reduction of CO_2 eq. per kWh is reached with the case of no additional CHP (-34%). In 2050 only the linear convergence leads to a relaxed reduction (-70%). The most stringent reduction is reached with the same decrease for all countries (-83%).

For the sensitivity in the final stage of the Multistage approach a clear trend can be seen. This is more obvious for 2050 than for 2020. Countries with high per-capita emissions have to reduce more radically on the group basis (where reductions are shared according to per-capita emissions) than on the country basis (where all countries reduce by the same percentage). For low-emission countries this trend is inverted.

Taking all the cases above, we see that the sensitivity calculations have an impact on the final reduction obligations for Finland. But most of the results of these tests lie within the range of the original Triptych 6 and Multistage calculations, which were calculated with only one parameter set but for six SRES scenarios. For 2020 only the high-emission base year, the inclusion of imports, some sector sensitivity calculations and the case of no additional CHP in the electricity sector lie outside of the original range. For 2050 some sector sensitivity calculations, the extrapolation of gross electricity consumption to be equal to national production, and the calculations in the last stage of Multistage have a higher deviation.

Although the Triptych approach has many possible parameters and requires input data that could be different, the overall necessary reductions are very similar, independent of the parameters and input data. In the short term (2020), only a change in the base year and the consideration of electricity imports could make a significant difference, but these are changes that are very unlikely to be acceptable to all countries in the future. In the long term even these changes do not significantly change the results.

For all of the approaches, the required reductions in 2020 and 2050 are of similar magnitude (-9% to -19% and -70% to -90% compared to 1990). Only the contraction and convergence case with convergence by 2100 requires less stringent reductions in 2020 and 2050, but this also seems to be an unlikely case. Most reductions are necessary for Multistage applying Triptych in the final stage of -85% to -87% in 2050. These results are independent of the possible parameters.

4. Evaluation of the Triptych 6 based on the case study of Finland

(Sampo Soimakallio VTT, Adriaan Perrels VATT)

4.1 General

The Triptych approach was originally developed to differentiate the emission allowances among Member States of the EU for the First Commitment Period of the Kyoto Protocol. The results of the approach were used as a basis for the negotiations of the final emissions targets for the Member States of the EU. The Triptych approach has now been extended to the global level and a time frame of 100 years. It is possible that this type of approach will be used also in further climate negotiations. This chapter presents the views and observations of the applicability of the current Triptych approach to be used for that purpose.

4.1.1 The dilemma between rigour and straightforwardness

From its inception onwards the Triptych approach was intended as a negotiation support tool, and consequently transparency, or rather straightforwardness, was called for. The fundamental problem with this kind of tool is the trade-off between the ability to consider national circumstances and a straightforward and transparent structure. The Triptych approach is a compromise between both types of desirable features. It lacks essential decision support model features when compared to complicated energy system or economic models, but thanks to its differentiation by sectors and countries, it is more sophisticated than a burden-sharing approach based only on per-capita emission level.

The Triptych approach represents a sector-based method of differentiating emission allowances. In order not to sacrifice straightforwardness, the model designers decided to avoid complicated dependences between parameters. Basically, it is only possible to specify certain variables as either growing or shrinking linearly, whereas these rates are allowed to differ by period. Essentially, everything is pre-set and hence consistency depends on the scenarios from which the data are taken. This, however, makes the approach more like a tool than a model, i.e. an emission attribution or accounting system, which restricts its applicability either to initial scans or to quick scans of a limited number of changes in an allocation plan, which was based on prior extensive modelling[3].

[3] . Ideally involving ensembles of climate models, ecological models and social-economic models.

4.1.2 Insight in efficiency – equity trade-off desirable

As indicated above and in section 2.1, Triptych 6 is a global emission attribution system. It starts from the assumption that stabilisation of global GHG emissions at 450 or 550 ppmv is indispensable, and that efforts are to be distributed according to purchasing power. The model design, which implies a pre-fixing of all essential growth rates without recourse to changes in the relative cost of alternatives, sectors or countries, does not indicate to what extent the resulting attributions of emissions are equitable and/or cost efficient. The model does not contain a test criterion, however approximate, that informs the user how far the resulting attribution of emissions is located from a certain benchmark level (representing the – allegedly – best possible trade-off between equity and cost-efficiency under given circumstances).

Given the intended key characteristics of the Triptych approach, i.e. straightforward and quick, the absence of such a test criterion is understandable. Yet the Triptych approach in its current state of implementation involves various strong assumptions regarding feasible additions to future electricity generation capacity and the convergence of per-capita emissions outside industry. As there is no cost-minimisation procedure in the model, one has to resort to this kind of strong assumption in order to keep the model simple and manageable. This means that, despite the very intent of accounting for an equitable and fairly cost-efficient strategy, there is no information whether the suggested pathways are actually offering a reasonable overall solution in terms of cost and equity. Elsewhere, attempts are made to include abatement and transformation cost and emission-trade-induced transfers between countries in comparable exercises (e.g. van Vuuren et al. 2003; based on a combined use of the FAIR, IMAGE, TIMER and RAINS models, Blanchard et al. 2003. based on the POLES model, Criqui et al. 2003, based on an even larger ensemble of models). The calculation of abatement and transformation costs introduces a further level of assumptions and complexity. Admittedly, these model systems would be less suitable for quick scans than the Triptych 6 system implemented in the EVOC tool.

Even though there are substantive reservations with respect to the way attribution of emissions is handled, the Triptych approach does clearly illustrate that Annex I countries should reduce their emissions radically regardless of the details of effort attribution. Consequently, unless one dismisses equity as a valid criterion, this illustration refutes views that aim to significantly postpone the establishment of long-term strategies, albeit indicative.

Another moderating aspect with respect to the critical remarks above concerns the shortcomings of other models, being either the models mentioned above or the various global and national general equilibrium models with energy-emission extensions (GEM-

E^3 models; Fankhauser and Tol 2005, (Tol 2002a-b), Nordhaus 2002, Kouvaritakis …). For really long-term simulations (i.e. well beyond 25 years) the uncertainties in these kinds of model exercises grow substantially. As a consequence, for very long-term simulations the models may produce diverging information when disaggregating more extensively by sector and country (group). This problem can be alleviated to some extent by searching for so-called robust reduction pathways. All things considered, the bottom line is that it should at least be realised that ignoring the influence of cost dynamics altogether entails a substantial risk, which is of a different nature than trying to find robust reduction strategies under uncertainty.

4.2 Key model design principles

The Triptych 6 system takes into account country-specific sectoral structures and current levels of emissions. This is an improvement compared to earlier versions. There are nevertheless high risks for mismatches in growth rates. The inserted (pre-fixed) growth rates for population, GDP, electricity demand, energy efficiency, etc. are derived from universally used scenarios (such as IPCC SRES). Originally, these growth rates were – as far as possible – tuned to each other's levels, albeit at the level of groups of countries (except for the largest countries separately included, such as the USA, China and India). However, the various IPCC scenarios in fact imply very different degrees of mitigation efforts, which are at least partly of an implicit nature. The Triptych approach on the other hand represents an explicit effort to reduce emissions vigorously. Yet, when such vigorous efforts are superimposed on the original growth rates of (most) scenarios from the IPCC SRES A1 and A2 scenario families, it will have a noticeable influence on many growth rates and hence the internal consistency[4] of the assumed growth rates gets easily lost.

Another source of increased risk for growth rate mismatch stems from the fact that the Triptych approach usually applies common rates to all countries in the same country group (even though there is the option to insert user defined deviations for single countries, as has been done for the Finnish test runs). There are, however, significant variations in affordable and/or feasible growth rates within country groups. The consequence is that at the single-country level, attributed emission reduction efforts could be unnecessarily low, or conversely be extremely expensive at the margin. This deviation could be aggravated due to the exclusion of local circumstances such as climate and geography.

As mentioned, the system allows the user to insert alternative rates. Such insertions may, however, just as well lead to increases in growth rate mismatches, since the

[4] . The internal consistency is often already of an approximate nature in many SRES scenarios.

Triptych 6 system is based on pre-fixed growth rates and it therefore depends on the extent that user-defined alternative rates have been tested for internal consistency. With respect to various growth rates the Triptych 6 system differs essentially from various other modelling systems for long-term emission reductions, such as the FAIR system or POLES, in which cost-minimisation is endogenous in the model.

Considering the possible[5] inconsistencies between original GDP growth rates and the adapted growth rates of industrial output and electricity demand, as well as accounting for possible tensions following from differences in unit-cost of abatement, both between national sectors and internationally, the results of the Triptych 6 system are shown in this report as a range over all SRES scenarios. The availability of results over a range of scenarios may assist in appreciating some of the sensitivities.

The Triptych approach accounts – albeit partly – for emission reduction measures already implemented. For various sectors this is done by applying similar requirements for all countries, such as the share of renewable energy sources in electricity production. On the other hand, the complete and far reaching strive for global convergence in emissions per capita is *assumed* to make differentiated convergence pathways for various countries less relevant. In other words, the distance to target (which is largely insensitive for country-specific features) predominantly determines the steepness of the rates of changes. Different endowments and starting points for natural resources, industrial specialisations, geographical conditions, and climatic conditions of individual countries have little or no influence on the emission allowances of the domestic sectors and the energy sector (considering its role in heating and cooling).

The sectors are handled individually in the Triptych 6 system resulting in the lack of connection between sectors. For instance, the electricity production figures are independent from electricity demand figures, and thereby also from the development of industry. This kind of independence is very unrealistic in the long run, and can lead to unrealistic forecasts regarding countries with large deviations from the regional average.

The base year, that is the year from which Triptych calculations depart, can be selected between 1990 and 2010. If the base year is set in the future (e.g. 2010 to analyse the Triptych approach after the Kyoto Protocol is implemented), the corresponding emission level has to be defined. The reference emissions have been extrapolated from current levels by using regional growth rates. Furthermore, the user can select whether the Kyoto targets are achieved, in which case the emissions are lowered equally in all sectors, except for the domestic sector, which is assumed to follow the related reference

5 . In fact the procedure in Triptych will almost certainly result in inconsistencies at this point. From a pragmatic point of view one could regard such inconsistency only as disturbing when it significantly affects the allocation of emission reduction efforts over countries. It remains however entirely unknown in the Triptych system whether such critical thresholds are surpassed in the resulting allocations.

scenario. This assumption may vary a lot from the actual development of those sectors, e.g. due to deviation between assumed and upcoming growth, and the implications of the EU's emission trading system. Therefore, it is not very suitable to select a base year which is situated in the future.

The parameter set which determines the pace of emission reductions is selected manually. It is in accordance with a certain global emission development path and a certain atmospheric concentration of greenhouse gases in a forecast year (2020, 2050, 2100), is selected manually. The sector analysis (section 3.2.2) illustrates that the differences between the original and selected (Table 6) sets of parameters is of 10 percentage points magnitude at maximum in the overall emissions of Finland in 2050. Even larger relative deviation is found for Sweden and for non-Annex I countries (Figure 8 and Figure 9).

4.3 Detailed critical features for Finland

4.3.1 Electricity production and demand methodology

The electricity consumption for upcoming years is derived from the gross electricity production figures of 2001 and multiplied by the demand growth rates corresponding to the selected reference scenario. This kind of approach is consistent with greenhouse gas reporting under the UNFCCC, but does not include the assumption of electricity exports and imports. Consequently, the share of electricity production of the overall demand in the base year (2001) has an impact on the electricity production figures for the upcoming years. The lower the net imports of some particular country in the base year are, the larger the calculated electricity production for upcoming years gets. Meanwhile, the approach is disadvantageous for countries which have been large net importers, but favourable for net exporters.

The same base year is also selected for the fuel mix of electricity production. The more a particular country has produced electricity in the base year, the higher the emissions from the electricity sector of that particular year are as well. This is also feasible for large net exporters, as the emission rights to use fossil fuels in the future are in proportion to the share of them in the base year. The impact of selecting the base year for the fuel mix was tested in the base year analysis (section 3.2.3). According to the test runs, the variation is of 2 percentage points magnitude at maximum in the overall emissions of Finland in 2050.

Due to the above-mentioned reasons, the impact of selection of the base year is emphasised. This impact was not tested directly, but can be assessed implicitly by means of the test presented in Figure 15. If all the electricity had been produced in Finland in 2001 in the selected base year with the corresponding fuel mix, the allowed national overall emissions in 2050 would have been roughly 8% higher, corresponding to some 3 percentage points in required emission reductions. This can be calculated from left-hand chart (Figure 15) by comparing absolute emissions including imports and emissions excluding imports in 2050 in proportion to absolute emissions excluding imports in 1990 . This comparison reflects a hypothetical case, in which net imports in the base year would have equalled zero. According to Finnish energy statistics (Statistics Finland 2003), the highest emissions of electricity production (28 Mt CO_2 eq.) and the highest share of domestic production in overall consumption of electricity (95%) between 1990 and 2001 took place in 1996 in Finland. If this particular year was selected as base year the further emission rights in the electricity sector would be the highest in Finland compared to selection of any other base year between 1990 and 2001.

Since the overall impact of selection of the base year on emissions depends both on the share of net imports and on the fuel mix, we suggest that some kind of average value from some representative period would be chosen instead of selecting only a single year as the basis for the calculations. In addition, as the Triptych 6 system assumes that there exist neither imports nor exports in the view years (e.g. 2050), we suggest that electricity demand figures would be used as the basis to calculate the upcoming demand, instead of power production figures. In due course under the chosen assumptions this reflects production as well.

4.3.2 CHP methodology

The methodology of handling CHP in the Triptych approach is problematic. The approach does not contain a definition for heat or steam demand, which has serious ramifications for the way emissions from CHP are accounted for. A very strict emission factor, being 70% of standard gas-fired-condensing power, is used for CHP. This implies an unrealistically high assumption for the production rate of power and heat. Consequently, there is no room for the "heat production part" of CHP. This approach results in a situation in which CHP is seen as an emission-reduction option, but cannot be used for that purpose. On the other hand, if a higher emission factor were used instead, allowing space for the "heat production part", the methodology would result in surplus emission rights for countries with small heat or steam demand. The more a country is already fully exploiting CHP, the more disadvantageous the approach gets.

To avoid the problems of the currently applied CHP methodology, we suggest that the requirement to increase the share of CHP would be replaced with the requirement to improve the overall efficiency of electricity production. The existing share of CHP should be taken into account when assessing the current total efficiency of electricity production. This can be done by separating the heat and power production parts of CHP from each other by using some allocation procedure (e.g. energy content). The efficiency of the heat production part can then remain untouched or be assumed to improve in line with the improvement of overall efficiency of CHP towards a certain long-term target.

4.3.3 Industry

As regards direct emissions from industry, in Triptych the development of the emissions is steered by the development of value added of the industrial sector. However, a structural change correction factor is applied to the original growth rates of industrial value added, as a means to represent a shift away from heavy industry, i.e. a unit of value added now is supposed to embody more emissions than a unit of value added in 50 years (in current prices). Currently, this structural change factor is uniformly applied for all countries without differentiation. In reality, however, factor endowments in various countries can seriously influence the evolution of the share of heavy industry.

In OECD countries, the abundant availability of primary energy sources, ores, logging wood, principal seaports and – a fortiori – combinations of these factors tend to attract heavy industry. On the other hand, consumer goods industries and services thrive better in populated regions. Considering these factors it should be no surprise that countries such as Norway and Finland end up with above-average shares of heavy industry. Even though the share of light industry and services is also growing in these countries, the point of departure is such that full convergence on an EU or OECD average is unlikely. The Triptych approach regarding industrial emissions, in its current mode of implementation, easily leads to a tight allotment of emission allowances for countries in which the structure of industry is turning away much less from energy-intensive industries than the EU or OECD average.

The realistic selection of value for the structural change index is of central importance. In the case of assuming unrealistically large or fast structural change, the related emission reductions that do not take place, due to lower or slower real structural change, should be carried out by some other way. These kinds of hidden emission-reduction requirements should be avoided. In addition, we recommend that the use of a differentiated structural change index for different countries or regions would be an option in the model.

The current level of industrial energy efficiency is assessed by using regional factors, resulting in uncertainty at the country or plant-specific level. In addition, the approach does not take into account the difference in the natural resource basis of countries, which has a significant impact on the possibilities and costs of reducing the carbon intensity of industry. Furthermore, the overall industrial emissions consist of both energy (fossil fuel combustion) and process-based emissions, whose contribution to overall industrial emissions may deviate significantly between countries. The reduction of process-based emissions may be relatively difficult or costly to implement without lowering production in countries that are already operating near the technical possibility frontier. Consequently, uniform requirements to improve energy efficiency cannot be equitable for all countries. From a theoretical economic viewpoint, this ties in with the previous point regarding the structural change factor. It is all related to the absence of relative cost levels in Triptych, which also means that variations in relative factor endowments (capital, volume and quality of labour, natural resources, land, human & social capital) are not taken into account.

The energy consumption of industry is mainly influenced by the structure of the industry, production activity level and energy efficiency. The annual emissions of industry may vary depending on the fuel mix and share of electricity in overall industrial energy consumption. Furthermore, unambiguous splitting of annual emissions between energy and other industry may be difficult in countries where the contribution of industrial power and heat production is significant. As a consequence, the Triptych 6 system handles part of the emissions from industrial steam production and from electricity production in electricity and in the industrial sector, respectively. This special characteristic is particularly relevant for Finland, but just as well for Germany and the Netherlands, among others. The implications of this feature depend on the mutual strictness of emission-reduction requirements set for both the electricity and the industry sector. Therefore, it is impossible to define whether the implications are advantageous or disadvantageous for Finland. However, we highly recommend that the same period of years be used in the definition of the base index year for both the electricity and industry sectors.

The rates of change of the energy efficiency index and of the index of industrial structure are set at the country group average and at the global level, respectively. Adaptation of one of these indicators (as is done for IVA in the Finnish test runs) should in fact be accompanied by the adaptation of the other as well, since industrial structure can seriously influence the overall trend in the average efficiency index.

4.3.4 Domestic sector

Even though no specific test runs were carried out for the domestic sector during the project, we regard the sector as sufficiently important to merit some comments. The reason for leaving this sector outside the test runs was the simple and unified emission-reduction target imposed on the sector, without possibilities for differentiation by country.

The requirement for emission reductions in the domestic sector is based on the global convergence of per-capita emissions in this particular sector. This means that national circumstances, such as climatic conditions and population density, are not considered. The actual possibilities and costs of reducing emissions in the domestic sector may vary significantly between countries. This kind of approach can be seen as disadvantageous for Finland due to the relatively cold climate, sparse settlement and long transportation distances. We recommend that the use of differentiated targets for per-capita emission convergence level would be an option in the tool. The national per capita convergence level of domestic emissions could be adjusted, for example, by applying country-specific degree-day corrections to the residential heating fuel requirement.

Alongside considering climatic conditions which greatly influence heating demand, it would be both consistent and equitable to consider the relation between climate conditions and cooling requirement as well. However, the required adjustments for accounting for heating and cooling demand respectively cannot be compared to each other in the Triptych approach. As the cooling systems are very typically electrically operated, the current use of those systems is actually accommodated in the consumption of electricity. Furthermore, electricity demand is assumed to increase in all countries, particularly in developing countries, which indicates that cooling expansion is implicitly considered.

The domestic sector as defined in the Triptych 6 system comprises building stock (emissions from local heating systems), domestic transport and international transport (bunker fuels). For 2020 the Triptych 6 system indicates a reduction of -22% for the domestic sector and for 2050 a reduction of -85%. The only guiding growth rate for this sector is total population (which – according to current expectations – will grow slightly up to 2020, and than reduces gradually for the rest of the century). It should be noted that the amount of floor space used in the service sector is actually more influenced by GDP and the purchasing power of consumers than by population as such. Furthermore, even though the total population will already start to decline in around 2020, the number of households and hence the number of dwellings will continue to grow up to 2040~2045 (Carter et al. 2005).

In all scenarios, but especially in the A1 and B1 scenario families, global trade is expected to grow vigorously. Given the lack of large-scale applicable emission-free propulsion technology in the short run (i.e. up to 2025), and considering likely continued growth in transport performance, international transport, and to some extent national goods transport by road, will already have great difficulties in keeping their emissions stable. Moderation of the emissions per ton-kilometre is only possible by optimising logistics, switching to low-emission modes and improving engine efficiency. The consequence of this is that most of the -22% reduction in 2020 should come from domestic passenger transport and the building sector. Together these segments represent a bit more than half of the emissions from the Triptych domestic sector, and hence -22% for the entire sector would mean about -40% for the segments of passenger transport and buildings.

To achieve such a reduction in the next 15 years is technically possible, but from a social and economic point of view extremely ambitious and expensive. As regards passenger cars, a mixture of measures including strict taxation, spatial planning and parking policies, as well as the promotion of public transport and bio-fuels may succeed in a reduction of -15%, perhaps -20%. Yet, in the absence of large-scale applicable and affordable breakthrough engine technologies, further reductions look rather unfeasible in this time span. Furthermore, the policy mix would be pretty expensive, i.e. implying high cost per abatement unit even though this might be attenuated to some extent by ancillary benefits, especially for urban environments.

The building stock renews at a slow pace and therefore this kind of target would necessitate intervention in the existing building stock. In Finland, for example, it would probably entail a mandatory replacement scheme for oil-based heating systems and price signals (taxes) that heavily discourage installation of oil-based heating systems in new buildings. A further complication might be that a good part of the heating system replacements would mean a switch towards electric heating. Even assuming it would mean heat pumps in all cases, this switch would not be emission-free, hence part of the problem is shifted to another sector. Furthermore, even though some of the replacements would probably not entail much extra cost, the large extent of replacement needed would almost certainly lead to very high marginal abatement costs in Finland.

Most certainly both for the car measures and the building measures it will apply that other sectors in Finland (notably energy conversion) could achieve reductions against much lower cost, at least for a part of the reductions now attributed to the domestic sector. A fortiori, the same applies when an international comparison is made. For example, there are few doubts that a similarly sized reduction potential could be found in the CDM and JI projects which would cost much less. As such the Triptych calculations do not preclude that part of the reduction targets are met by emission trade. However, even in that case it still matters that various buying countries are facing purchase obligations with similar underlying cost logic. Yet that cannot be checked by means of the Triptych 6 system. Similarly, the Triptych 6 system allows the user to deviate from standard assumptions and, for example, relieve the burden of one sector (as has been tested in chapter 3). However, if this were to be done for a multitude of countries, the preparatory work would become substantial, and consequently the advantageous position that Triptych could have for running quick scans would be lost.

These examples illustrate in a nutshell what kind of misuse the approach may lead to. This is largely due to the pre-fixation of various rates as well as the absence of cost variables in the system. Obviously, the kinds of deviations discussed here do not only apply to Finland, but in principle apply to all countries. At the level of country groups this problem will often be somewhat less problematic. In that respect it may be worthwhile to consider focusing model development work on better representation of sectors, more distinction between sectors, construction of some linkages between variables (growth rates), effort-sensitive indicators for average and marginal abatement cost per sector per country group (just indicators, not equalisation etc.).

5. Concluding remarks

(Sampo Soimakallio VTT, Adriaan Perrels VATT)

5.1 General

The Triptych approach represents one of the most sophisticated methods that has been used as a negotiation tool to differentiate emission allowances. The purpose of this kind of tool is to provide preliminary indicative amounts for emission rights, which are then negotiated. Burden-sharing approaches should represent fairness in a way that can be broadly accepted. Consequently, the results of such methods should not gravely misrepresent capacity to reduce emissions. As transparency is typically claimed for such negotiation tools, the ability to consider different types of national circumstances easily decreases.

The main advantage of the Triptych approach compared to simpler methods, such as burden sharing purely based on per-capita emissions, is the ability to better take national circumstances into account. However, due to the large amount of various assumptions and data sets required in the Triptych approach, the transparency is at least partly lost.

The Triptych 6 system considers the sectoral structure and current level of emissions of each country. Since the fundamental principle of the approach is sectoral efficiency convergence in the long run, whereas this is combined with straightforward linearised development by sector and country, no country-specific emission pathways can be simulated. This kind of characteristic effectively restricts the ability to consider national circumstances, such as natural resource endowment, structure of industry, residential heating demand, etc., in as far as these deviate significantly from default values by sector and/or country group. These differences may not be so pertinent at the regional level, in which case the approach is more suitable to differentiate emission allowances between country groups or large countries than at the national level. However, when applying group level analysis only, it is important to realise that in the actually applied grouping of countries some groups (e.g. Oceania and some Asian groups) contain a very large spread in wealth levels.

The independence between sectors in the Triptych approach may lead to relatively strict or mild emission targets for those countries whose sectoral development does not go along the average development assumed. For example, the lack of connection between industrial growth and electricity demand may lead to under- or overestimation of electricity demand in the future. The risk of this kind of distortion becomes more relevant particularly in the long run. Therefore, we suggest that the time frame of application should be relatively short (maybe 2015–2020) and the use in the longer term only for indicative purposes.

The global coverage and the distinction between various sectors, in conjunction with the possible distinction down to the country level, results in a very extensive data system. As a consequence there is a tendency to assume many parameter values as being equal for many countries or even constant, in order to keep the data system manageable. However, with a data system of such scale and diversity, with input from a large diversity of sources with varying data quality control, it becomes very demanding to maintain data quality and to actually implement diversity in parameter values. In fact the combination of a large catchment area with arithmetic simplicity starts to work against the point of departure of simplicity and transparency. The model users and database managers end up doing work that models with more built-in intelligence would take care of themselves, and after a validation period would start to make many fewer errors than a system which takes a lot of human intervention.

5.2 Specific considerations for Finland

The test runs of the Triptych 6 system did not principally indicate large differences (less than 10 percentage points) in results between the different sets of parameters. This does not, however, mean that the approach would not be sensitive to uncertainties. The planning and feasibility of the test runs were restricted by the methodology of the approach, and the test runs were carried out without any remarkable changes in the methodology. As illustrated in Chapter 4, methodological changes enabling enhanced considerations of national circumstances may have more significant impact on the results.

The most critical methodological features of the Triptych 6 system for Finland are defective consideration of CHP in overall electricity production efficiency, the sensitivity related to the base year selected for fuel mix and growth of electricity production, the lack of separation between energy-intensive and light industry, as well as purely per-capita-based emission reduction targets set for the domestic sector. The description of these issues in the Triptych 6 system does not adequately accommodate the large share of CHP utilisation, annual variation in electricity imports, relatively energy-intensive structure of industry, cold climatic conditions or sparse population.

5.3 Implications for the use of Triptych in the future and suggestions for further development

The abolishment of relative cost information regarding the choice of technologies in different countries comes with the price that the resulting pathways cannot be judged on the extent to which attributed reduction obligations imply similar or very different cost levels for countries with very similar wealth levels and emission intensity levels. With an eye to the intended use as an explorative tool in the margin of negotiations, it should be stressed that inadvertent misplacements of a first shot for some parties in discussions regarding long-term emission reductions may be hard to correct in later stages.

The Triptych 6 system requires a lot of sectoral data and uses some iterative processes to solve the growth rates for electricity and industry. Consequently, this approach is after all much less transparent than one would expect. It arises a question of why not to use even more sophisticated approach. The extension of sectoral split and the use of more specific data and differentiated parameters would probably aggravate the transparency to some extent, but also improve the confidence of the results.

Firstly, the regional results of the Triptych 6 system could be compared to the outcomes of more sophisticated models also considering the economic implications of emission reductions. This kind of analysis would assist in confirming the results and in recognising the possible need to implement certain simple methodological changes in the Triptych approach, such as the possibility to use more differentiated parameters. As a consequence, the Triptych 6 system could utilise the results of more sophisticated models without making the approach much less transparent.

After this kind of procedure to check the Triptych 6 system, the approach would be more suitable to being applied for burden sharing at the regional level. The adequate applicability at the country level is, however, much more difficult to achieve, as there is no uniform country-specific data available globally. More detailed data may be available between countries within certain country groups, e.g. between Member States of the EU. Consequently, the differentiation of emission allowances between countries inside the group could be carried out by some more sophisticated method accommodating more country-specific circumstances. If a Triptych-like system is intended to be used for burden sharing at the country level, we suggest that the flexibility and data quality control of the approach would be enhanced significantly.

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Appendix A: Checking the EVOC tool

The project partners VTT, VATT and Ecofys undertook several checks during the project as an extensive review of the EVOC tool, with which the calculations were done. A full description of the model is included in Höhne and Ullrich (2005). The results of these checks are presented in this section.

Comparison of the underlying data of the EVOC tool

We compared the underlying data of EVOC with the original SRES data and the SRES data calculated with the IMAGE 2.2 model by RIVM (the National Institute for Public Health and Environment, Netherlands) (IMAGE team, 2001). These three data sets differ in their degree of detail. The IPCC provides data for four world regions. In the IMAGE 2.2 model these data are split up further for 17 regions. The latter is the direct data basis of the EVOC tool which uses them split up to country level.

Because of the differences in the gross domestic product (GDP) and population growth rates between the EVOC data and the Finnish data, this comparison should make sure that the different ways of calculating the SRES data did not lead to major changes or inconsistencies in the data sets. Figures A1 to A3 show that the global growth rates especially until 2050 match comparably well for all three models. Some higher deviations can be observed mainly for GDP growth rates in A2 and B2 (see Figure A3). But even these have a relatively small range.

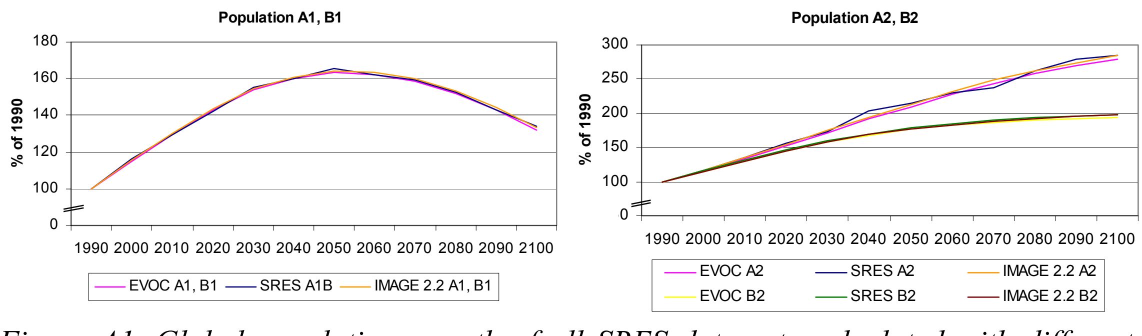

Figure A1. Global population growth of all SRES data sets calculated with different Models.

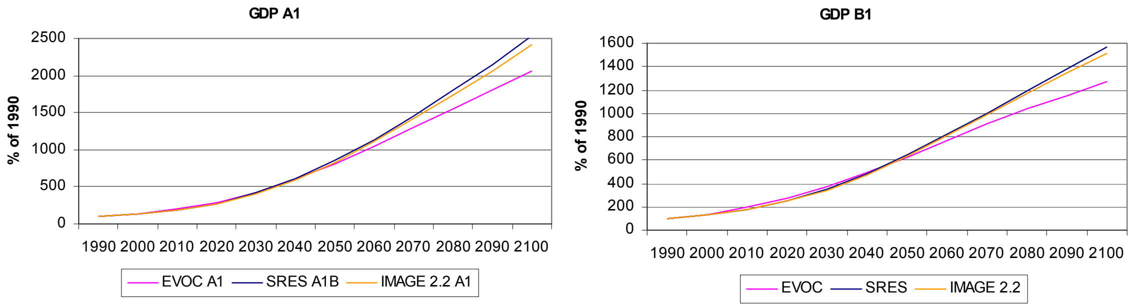

Figure A2. Global GDP growth of the SRES A1 and B1 data sets calculated with different Models.

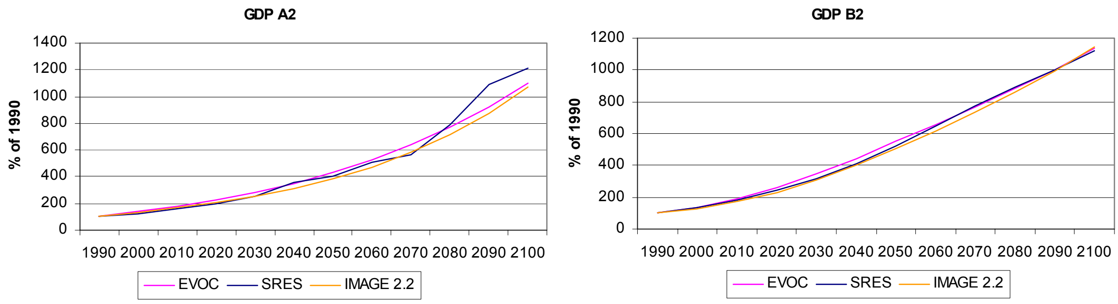

Figure A3. Global GDP growth of the SRES A2 and B2 data sets calculated with different Models.

Electricity GDP elasticity

We checked the elasticity of energy consumption in relation to GDP. These values are included in the EVOC tool as provided by the RIVM IMAGE model. We did not manipulate these data. We also found an elasticity of above 1 for the A2 scenario, which means a higher increase in electricity demand than in GDP. This is unusual but it is the implementation of the IMAGE model.

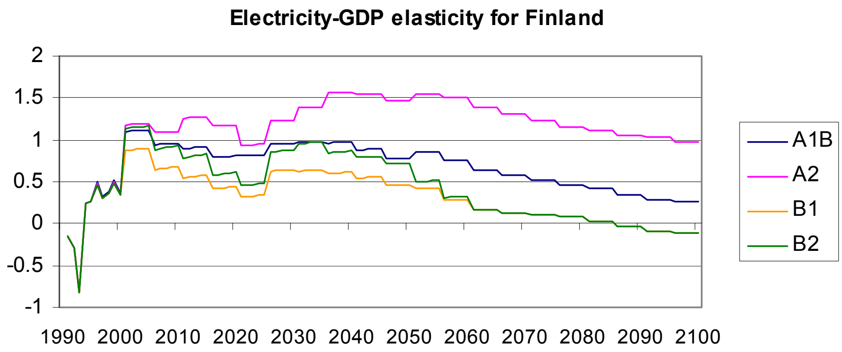

Figure A4. Electricity-GDP elasticity for Finland.

Comparison of country-specific GDP and population data for Finland

The growth rates for Finland used in the EVOC tool do not match exactly the national growth rates provided by Carter et al. (2005) (see Table A1 and Figure A5). The EVOC tool uses the growth rates provided in the RIVM IMAGE implementation of the SRES scenarios for the region "OECD Europe", and applies them to the data available for Finland.

The period of major importance for the results in EVOC is the years 1990 to 2050. In 2050 the population growth rates result in a deviation of +9.6 percentage points (A1B, A1T, B1) and +15.5 percentage points (A2) of the EVOC data compared to the Finnish. The GDP growth rates used in EVOC result in a deviation from -12.6 to +10.8 percentage points until 2050. In comparison with the 100% increase until 2050, these deviations are relatively small. These divergences become more significant but also more speculative in later years.

But we expect these differences between the Finnish and the EVOC data sets to be of no significant importance for the final results until 2050, since it is always reasonable to regard the corridor of possible developments the SRES scenarios create (see also section 3.2.1).

Table A1. Comparison of GDP and population growth rates between Finnish estimations and the data applied in EVOC for Finland (Estimates for Finland taken from Carter et al. 2005).

		Estimates for Finland				EVOC data for Finland			
SRES scenarios	Annual growth rates for Finland	1990-2020 [%]	2020-2050 [%]	2050-2100 [%]	Index 2100 (1990=100)	1990-2020 [%]	2020-2050 [%]	2050-2100 [%]	Index 2100 (1990=100)
Global markets A1B A1T	Population	0.28	-0.18	-0.33	86	0.31	0.08	-0.16	104
	GDP	2.25	2.10	1.30	677	2.36	1.87	1.63	788
	GDP per capita	2.00	2.30	1.65	792	2.04	1.78	1.79	757
Retrenchment A2	Population	0.28	-0.18	-0.33	86	0.37	0.20	0.32	139
	GDP	1.65	1.05	1.00	368	1.83	0.90	1.02	374
	GDP per capita	1.40	1.20	1.35	424	1.45	0.71	0.70	269
Sustainability B1	Population	0.28	-0.18	-0.33	86	0.31	0.08	-0.16	104
	GDP	2.10	1.50	1.30	556	2.32	1.40	0.84	459
	GDP per capita	1.80	1.70	1.65	642	2.01	1.31	1.00	441

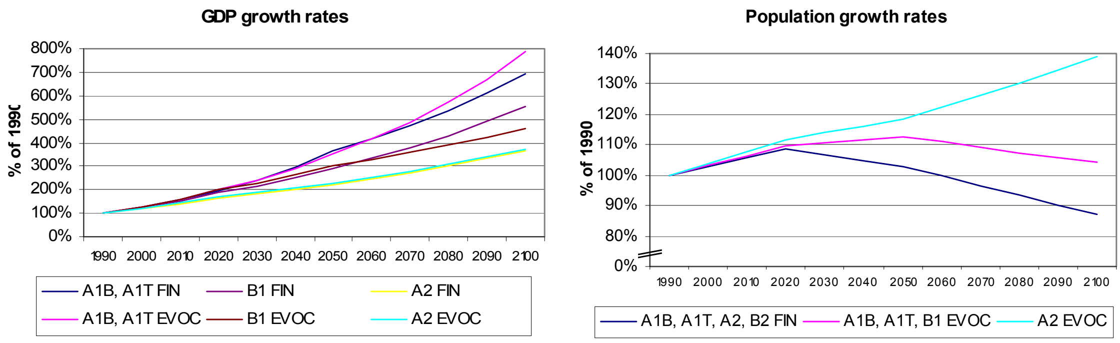

Figure A5. Population growth of all SRES data sets calculated with different Models.

Review of the Triptych calculation

During the review under this project, we found mistakes in the implementation of the Triptych approach that we use in the EVOC tool. The calculations of the electricity sector and of the agriculture sector in the Triptych approach lead to slightly different results than we intended. The reasons for the error in the electricity sector were the use of different growth rates, an error in the 'negative gas correction', and similar converging efficiencies for CHP and gas. In the agriculture sector the emission reduction rates for low and high-income countries were interchanged.

We planned to take the outcomes of the previous report as the base case for the sensitivity analysis. As a consequence of correcting the mistakes, the data we used in the first report calculated with Triptych 6.0 (Höhne and Ullrich, 2005) are slightly different to the new Triptych 6.1 data applied in this report.

We used the same configurations as in the first report as far as possible for all calculations in this report. With the same Triptych parameters, global emission reductions of +31% compared to 1990 are achieved for the 450ppmv path in 2020 with Triptych 6.1, compared to +26% with Triptych 6.0. Until 2050 -31% are achieved with Triptych 6.1, compared to -30% with Triptych 6.0. The differences for single countries may be higher.

For the Multistage approach applying Triptych in the final stage no important global changes can be seen between the two versions until 2020. Until 2050 only -17% emissions reduction compared to -21% in the original Multistage calculations are reached with similar configurations. The reduction efforts of the Annex I countries increase slightly but the emissions of the Non-Annex I countries increase considerably for the chosen settings.

Figure A6 to Figure A9 show the differences in emissions for the two Triptych versions in 2020 and 2050. Due to lower combined heat and power (CHP) emissions in the latest version, the emissions until 2050 are lower, especially for Annex I countries. The change in agriculture emissions causes Annex I countries' emissions to decrease further, while the emissions in Non-Annex I countries increase slightly. These trends cannot be seen as clearly in 2020.

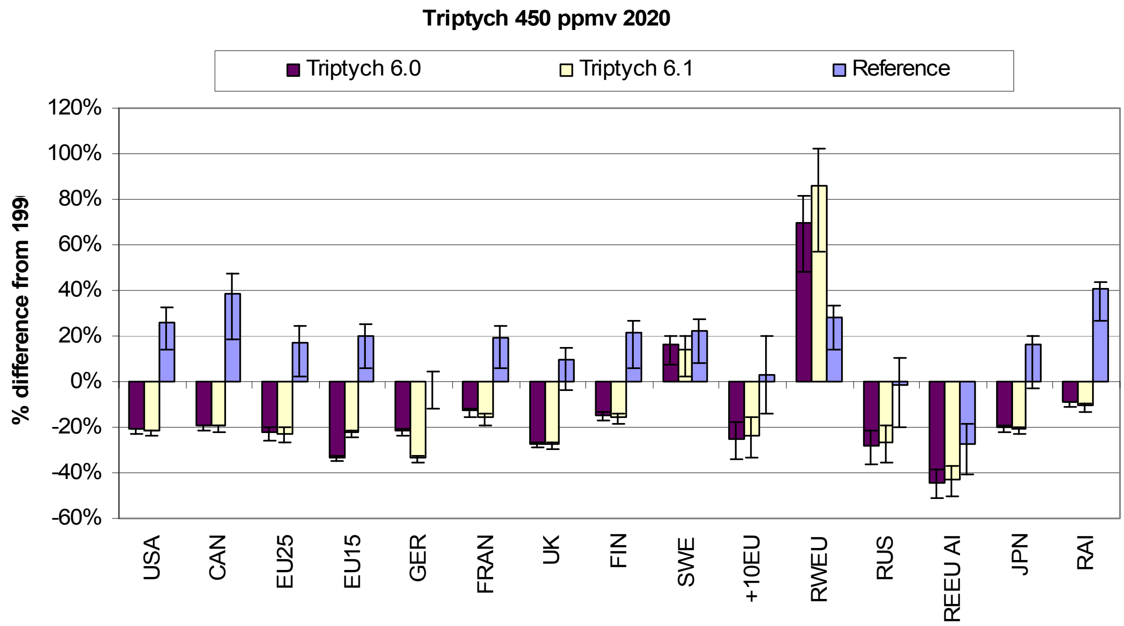

Figure A6. Change in Annex I emissions from 1990 to 2020 in the 450ppmv scenario: Comparison of the two Triptych versions as applied in EVOC. Ranges are due to the use of the six SRES scenarios.

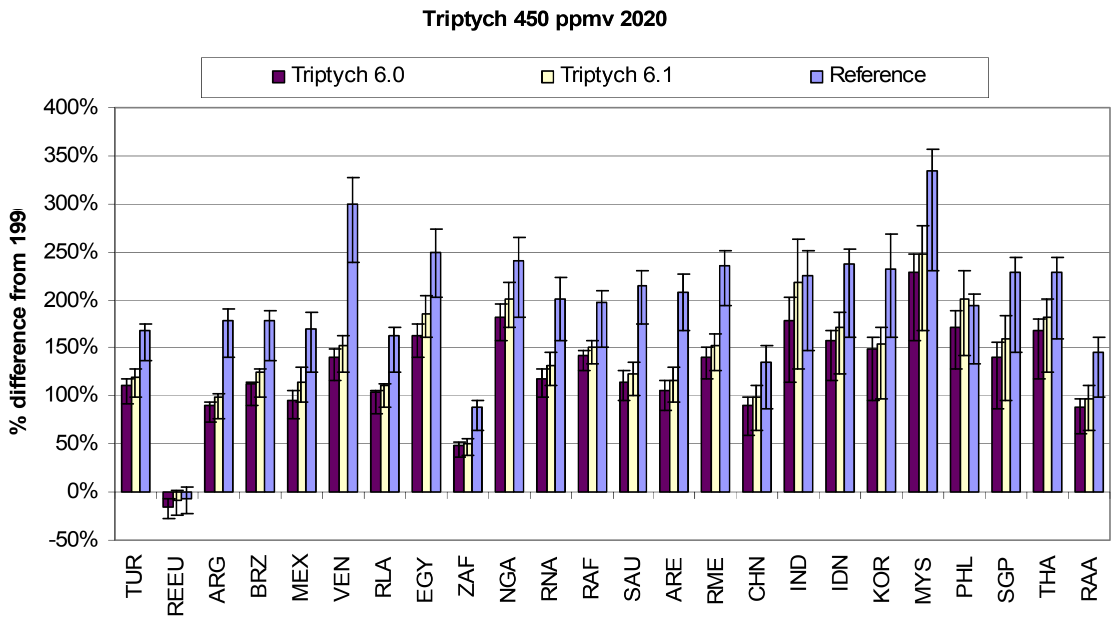

Figure A7. Change in Non-Annex I emissions from 1990 to 2020 in the 450ppmv scenario: Comparison of the two Triptych versions as applied in EVOC. Ranges are due to the use of the six SRES scenarios.

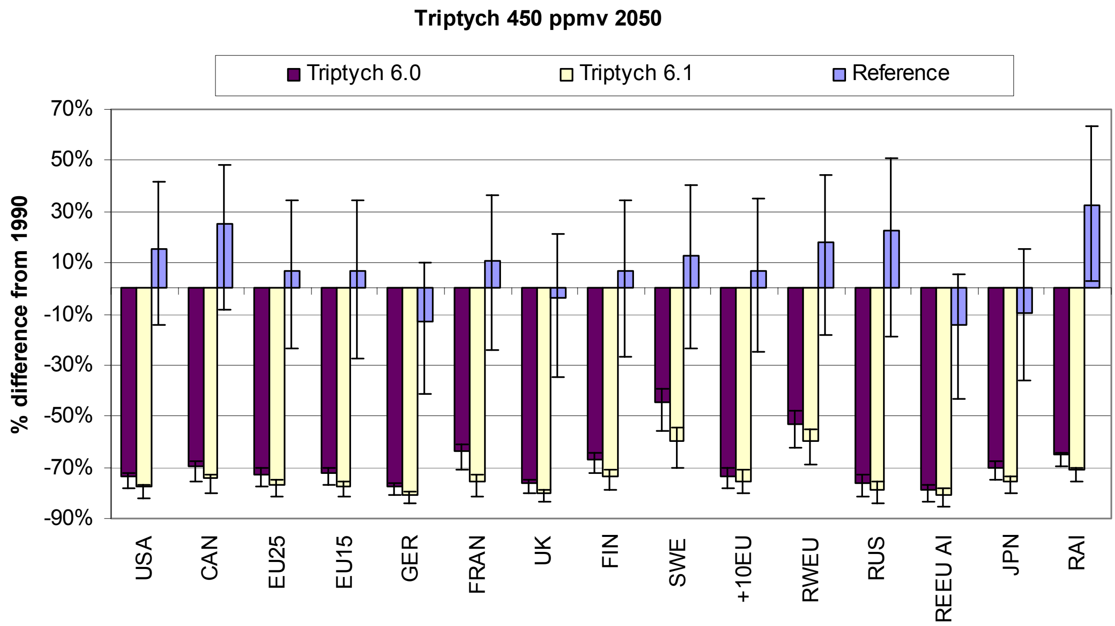

Figure A8. Change in Annex I emissions from 1990 to 2050 in the 450ppmv scenario: Comparison of the two Triptych versions as applied in EVOC. Ranges are due to the use of the six SRES scenarios.

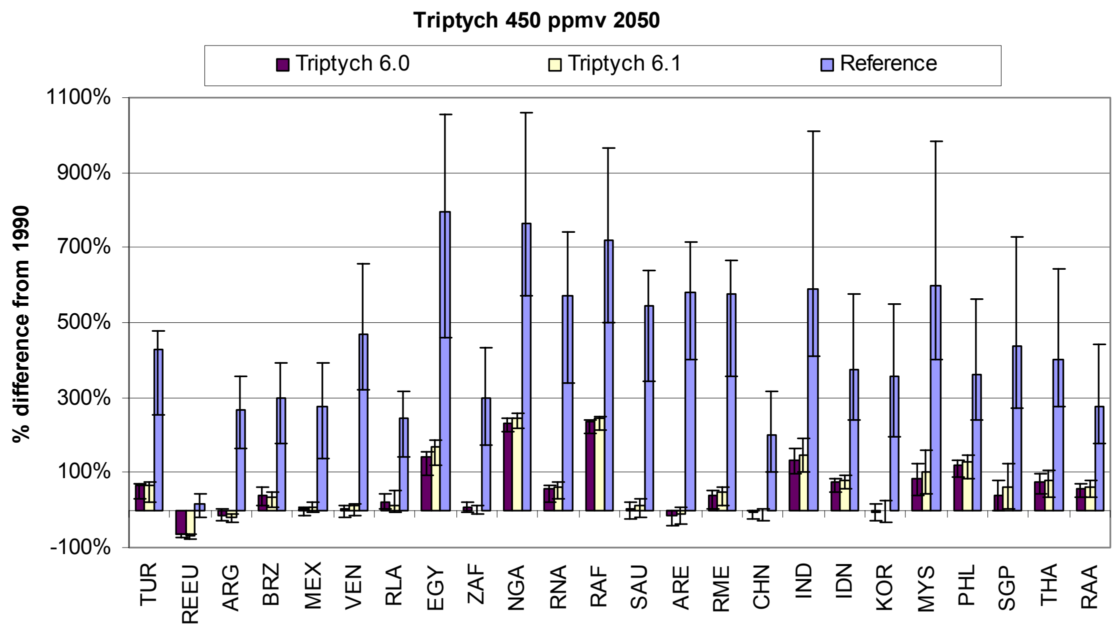

Figure A9. Change in Non-Annex I emissions from 1990 to 2050 in the 450ppmv scenario: Comparison of the two Triptych versions as applied in EVOC. Ranges are due to the use of the six SRES scenarios.

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