Equity and Carbon Emissions Trading: A Model Analysis

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Abstract

Carbon emissions trading is a key instrument of climate policy. It helps to bring about emission reductions in that place where they are least costly. However, fair burden sharing is about more than just cost-efficiency. While focussing on the instrument of emissions trading, this paper touches upon equity issues that frame decisions on emission rights allocation. The analysis is based on the ICLIPS model. The model study gives new insights on how the equal per capita allocation principle influences the intertemporal emission paths and about the distribution of mitigation costs in the long run. Apart from the intuitive economic evaluation of model results, this paper also attempts to provide an evaluation from an equity point of view. For a variety of assumptions, model results show that several developing countries could benefit considerably from joining an international emissions trading system, thereby becoming potential collaborators in post-Kyoto climate policy agreements.

Keywords: climate policy, emissions trading, equity, integrated assessment

1. Introduction

In climate policy decision-making, pure economic decision criteria are superimposed by fairness issues. This applies in particular to the instrument of emissions trading. Both the question of whether to restrict the amount of emission permits traded and the question about the principle of emission rights allocation can in part only be answered by looking at equity and other non-economic factors. Most climate policy models are not able to reflect such non-economic factors and their influence on decision-making in an appropriate formalized way. Since they are not equally represented in the models, economic and non-economic factors can not be traded off against each other. They are of rather different dimensions. Consequently, existing models fall back on economic analysis and handle equity issues by means of exogenous normative assumptions. This is the point of departure in the present analysis too. However, model results will be subject to supplemental evaluation focussing on interregional equity.

The international literature has discussed the equity issue in the context of climate policy burden sharing and emissions trading for some years (e.g., Rose and Stevens, 1993; Manne and Richels, 1995; Ridgley, 1996; Ringius et al., 1998; Gupta and Bhandari, 1999; Azar, 1999; Helm, 1999;

Aaheim, 1999; Metz, 2000; Carraro, 2000). I focus on a prominent allocation-based equity criteria - the equal per capita emission right - which follows from the egalitarian approach (see Rose et al., 1998). The equal per capita entitlement to emission permits is not the only method of allocation that can be justified by equity concerns and it fails where different individual needs arise due to existing natural and cultural living conditions. Therefore a combined allocation principle is probably more equitable (Müller, 2001). Nevertheless, the moral superiority of the equal per capita allocation of emission permits follows from the global commons property of the atmosphere as a sink for anthropogenic greenhouse gases and its limited sink capacity. There are no property rights to the atmosphere, so anyone is eligible to use it. This is the current legal situation as long as international agreements are not violated. However, overproportional per capita emissions today restrict the future emission opportunities of others. Hence the argument against the equal per capita allocation, that the others are unable to use a surplus of emission rights anyway, is unconvincing. Overproportional use thus only seems fair if the others are compensated, which is something that could efficiently be implemented by means of an emissions trading regime.

Most model studies analyze the impacts of an equal per capita allocation of emission rights in a rather limited form, e.g. without the tradeable permit market being explicitly modeled (Edmonds et al., 1995) or by fixing the emission reduction targets ex-ante, which not only applies for studies that aim to model the consequences of the Kyoto Protocol, but also for studies with a time horizon that goes beyond Kyoto (e.g., Rose et. al., 1998; Böhringer and Welsch, 2000). Buonanno et al. (2001), who analyse the impact of emission trade restrictions on equity and efficiency, implement the allocation of emission permits by assuming that the Kyoto targets apply for the whole century. While focussing on long-term climate policies, the model study presented here goes beyond this rather unlikely Kyoto-for-ever scenario. It resembles the ‘contraction and convergence’ approach (Meyer, 2000) and derives the global as well as regional emission reduction targets from the model analyses based on a permit market and on ambitious climate goals. Due to this, I am able to give new insights on how the equal per capita allocation principle influences both the distribution of mitigation costs and intertemporal emission paths (“when flexibility”). Moreover, I will demonstrate the phenomenon of the “equity dent”, which arises under a particular model setting.

With a given reduction target and under common assumptions on rationality and competition, model studies yield a market solution according to which all regions have to reduce greenhouse gas emissions up to the point where the marginal abatement costs reach the same level. While neglecting any equity aspects, Nordhaus and Boyer (1999) based their analysis about efficient climate-change policies on an emission rights allocation that follows that market solution (they call it a revenue-neutral allocation). Emissions trading will hardly occur in such a model setting. Above all it implies different reduction amounts (in absolute as well as percentage terms) for each region, while the responsibility of major emitters is not taken into account. It is far from being a realistic option to expect that African countries undergo emission reductions because of their low mitigation costs without any compensation. A differentiated burden sharing as demanded by the Kyoto Protocol is required. Nevertheless, the efficiency potential offered by the market can yet be used thanks to flexible instruments like emissions trading.

There are two approaches to starting the emissions trading system. With the first approach, a given amount of emission rights is auctioned, whereas according to the second approach emission rights are allocated on the basis of a fixed allocation rule. While in the second case the discussion is centered around the allocation rule, the same applies to the problem of recycling the revenues from auction in the first case. In the present model, I start with an initial allocation of emission rights. But differently to other studies, I do not derive this allocation from fixed regional emission reduction targets. Only the regions' share in the pool of emission rights is given. The absolute level of allocated emission rights is endogenously determined.[1]

2. Model framework

The analysis is based on the version 1.0 of the ICLIPS model (Toth et al., 2003). The ICLIPS model serves to integrated assessments of climate protection strategies. The core model, that is used for this analysis, couples an economic submodel (cf. Leimbach and Toth, 2003) and a climate submodel (cf. Bruckner et al., 2003)[2]. The economic submodel (ICEMODE) is described in Figure 1, a technical description is presented in Appendix A. ICEMODE is a multi-region, single-sector economic growth model. In the following I describe the most important assumptions that frame the model analysis.

The starting point is a definition of guard-rails[3] which should exclude intolerable developments of the climate system. In a cost-effectiveness analysis, the model determines that emission path which keeps the system within the guard-rails at least costs. The chosen guard-rail is a climate window that restricts the increase in global mean temperature to 2˚C (relative to the preindustrial level) and the rate of change in global mean temperature to 0.2˚C per decade.

Drastic emission reductions within each region are required to meet this guard-rail which was originally defined by the German Environmental Council on Global Change (WBGU, 1995). In an economic growth model, emission abatement is optimally allocated regionally and temporally. Emissions trading makes the system more flexible and thus increases economic performance. The

1. The intended long-term analysis goes far beyond the time horizon of the Kyoto Protocol. Short-term adaptation and mitigation measures are not the focus here. Hence, I do not attempt to base the analysis on the specific reduction targets as announced by the Kyoto Protocol.
2. The submodels of ICLIPS are also elements of PIAM (Potsdam Integrated Assessment Modules) which represent a highly innovative framework of modularized model integration. PIAM activities were started at the Potsdam Institute for Climate Impact Research recently.
3. See Bruckner et al. (1999) for a detailed discussion of the guard-rail approach.

actual level of trading, however, depends on the initial allocation of emision rights. Regarding the allocation principle I will focus on the equal per capita distribution. Although representing a fair principle in the long run, in the short term the per capita distribution seems to have hardly any chances of implementation. The underlying argument is that of the economic cost. I carried out a series of experiments in which I calculated these costs while varying the model setting in two directions. First, I combined the equal per capita allocation with a status quo rule (see Eq. 28 in Appendix A), and second, I analyzed the impact of emission trade restrictions.

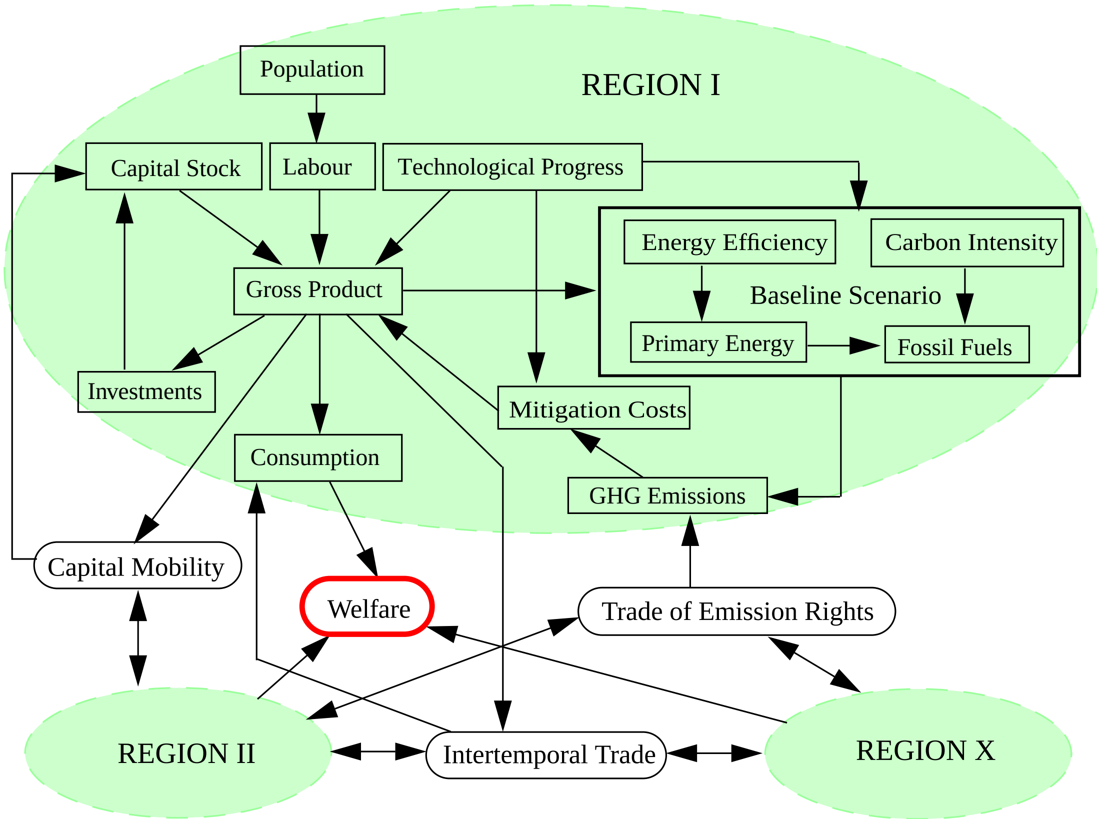

Fig. 1: Structure of ICEMODE

In modeling the initial allocation of emission rights I decided on a static basis, namely the projected population shares in 2025. This means that after the transition phase from status quo allocation of emission rights to equal per capita distribution, each region's share in the entire pool of emission rights is equal to its population share projected for 2025. While this implies some degree of imprecision, in contrast to the more usual application of base year population shares, choice of the later benchmark does not penalize regions with high population growth rates[1]. It, however,

1. The overall demographic trend of the next 20-30 years is determined by the current age structure of population.

provides enough stimulus to an active demographic policy that can be effective only in the long run. Within the model analysis, Annex-I countries enter the emissions trading regime in 2000, non-Annex-I countries participate in emissions trading from 2010 onwards. Emissions trading can be constrained. Whereas sale restrictions are related to the allocated amount of emission rights, purchase restrictions are related to the effective emission level. This differs from the supplementarity approach (cf. Rose and Stevens, 2001) which set purchase limits in relation to substantiated domestic emission reductions.

Additional flexibility of the modeled emissions trading system results from the divergence of obtaining and paying for emission rights. Actually, there are two separate trading flows - the exchange of physical emission rights (measured in Gt C) on the one hand, and the exchange of the composite good (measured in $US) on the other hand. Both trading flows are linked via an intertemporal trade balance[1]. Any purchased unit of emission right has to be repaid either in the form of emission rights (however not equivalent in physical terms, but in present value terms) or composite good. Banking of emission permits is not allowed for this model analysis.

The cost of carbon dioxide mitigation is measured as loss of regional gross product. ICEMODE calculates the mitigation costs based on dynamic mitigation cost functions which include learning effects. The foundation of this functional type is discussed in Gritsevskyi and Schrattenholzer (2003). Within the ICLIPS model only CO_2 is handled as a control variable. This is due to the fact that no reliable estimates for the mitigation costs of non-CO_2 greenhouse gases exist internationally. Furthermore, it is assumed that the major part of CO_2 emission reduction has to be performed in the 21st century (from 2105 onwards emissions are kept constant). Nevertheless, the climate submodel of ICLIPS takes into account the radiative forcing of all major greenhouse gases (cf. Bruckner et. al, 2003). Additionally, the cooling effect of aerosols, which is caused by SO_2 emissions, is taken into account. SO_2 is on the one hand coupled to CO_2 (same percentage increase and reduction) and on the other hand is subject to an autonomous desulfurization process which amounts to 1.0% per year.

1. A model solution is found after a sequence of joint optimization runs where a global welfare function is maximized. Between each single optimization run intertemporal trade balance deficits are computed for each region by evaluating the permit trade and composite good trade flows. Shadow price information is used for this. Regions with trade balance deficits lose weight within the global welfare function. This so-called negishi iteration mechanismus (cf. Leimbach and Toth, 2003) is deployed until all intertemporal trade balance deficits are equalized.

3. Baseline assumptions

Exogenous emission scenarios are assumed for the non-CO_2 greenhouse gases. As regards CH_4 and N_2O a rather optimistic view is adopted by assuming that the emission levels of 1990 are kept constant. In comparison with emission scenarios of the IPCC (Intergovernmental Panel on Climate Change), which project increasing emissions in the business-as-usual case, this scenario implies “free lunch” mitigation options. Carbon dioxide emsissions from land-use change follow the IPCC scenario IS92a (Leggett et al., 1992).

The baseline of industrial carbon emissions is based on the IIASA reference scenario F (cf. Gritsevskyi and Schrattenholzer, 2003). This scenario is similar to the A2 scenario of the World Energy Council and resembles the fossil-fuel-intensive version of the A1 family of the IPCC SRES scenarios (Nakicenovic and Swart, 2000). The present reference scenario is a growth-oriented, emission-intensive scenario. Coal continues to play an important role in providing energy throughout the whole of the next century. The proportion of the renewable energy bases increases by the year 2100 to around 40%. World-wide industrial carbon dioxide emissions increase up to around 25 Gt C in 2100.

The model differentiates between 11 regions:

AFR	-	Sub-Saharan Africa
CPA	-	China, Mongolia, Vietnam, Cambodia, Laos
EEU	-	Eastern Europe
FSU	-	Former Soviet Union
LAM	-	Latin America & the Caribbean
MEA	-	Middle East and North Africa
NAM	-	North America
PAO	-	Pacific OECD (Japan, Australia, New Zealand)
PAS	-	Other Pacific Asia
SAS	-	South Asia (mainly India)
WEU	-	Western Europe.

For each of these regions Gritsevskyi and Schrattenholzer (2003) derived regional mitigation cost curves suited to the reference scenario. These estimates, which are applied here, indicate comparatively high mitigation costs for CPA, FSU and MEA, and rather low costs for AFR, LAM and WEU.

In accordance to the reference scenario, significant differences in the future economic dynamics are projected:

- moderate growth on a high level: NAM, PAO, WEU,
- accelerated growth: EEU, FSU, PAS,

- medium growth: CPA, MEA, LAM (it should be noted here that within the short term CPA demonstrates the greatest dynamics and realizes entry into this "middle income group", while MEA and LAM are more likely to lose their place in group 2 as a result of slowdown of growth),
- delayed growth: AFR, SAS.

4. Equity dent

The applied model distinguishes between emission permits and actual emissions. The meaning of this distinction is straight forward at the regional level. At the global level, however, one would expect that emissions and the amount of permits are equal since banking is excluded. Figure 2 illustrates a particular implication of assuming global emissions and global permits to be either equal (i.e. permits have to be used up completely) or unequal (i.e. unused permits are possible).

Both emission paths presented in Figure 2 result from policy runs which include the above mentioned guard-rail and a particular configuration of the emissions trading regime. Under this regime emission rights purchase is restricted to 50% and the equal per capita allocation rule is enforced to take complete effect in 2025. However, whereas the dashed line is obtained from a model that allows global permits to be greater than global emissions, the solid line results from equalizing global permits and global emissions. The solid line represents a rather atypical, globally more costly emission trajectory which in contrast to the usual course of an optimal emission trajectory (represented by the dashed line) first decreases and afterwards rises. I call this property of the global emission trajectory an equity dent.

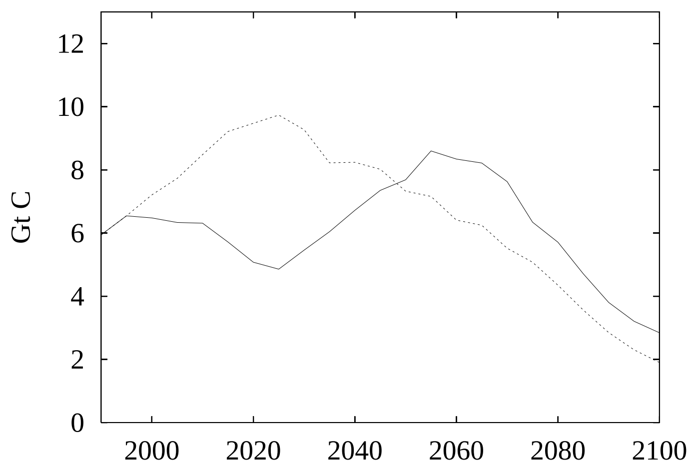

Fig. 2: Global carbon dioxide emissions (industrial)

It is evident that the equity dent does not result from the impact of the climate window guard-rail, but is forced due to the implicit precondition of adjusting regional per capita emissions in 2025 while not allowing unrestricted trade and unused emission rights. Under these conditions a maximum level of per capita emission rights exists for each region[1]. The lowest figure of these maximum values poses in each period an upper limit of allocation to which each region due to the distribution principle have to converge. With the equal per capita allocation principle taken full effect, multiplying this figure with the world population number results in the volume of globally disposable emission rights. The equity dent occurs, if this result is lower than the amount of emissions that is allowed by the climate window. In this case, the slow down of the emission trajectory before 2025, which reflects dratsic emission reductions of the high per capita emitters in order to approach the lowest maximum per capita emission rights level, is not reasonable.

While the equal per capita rule should be part of an active climate policy that aims at a lower level of climate change impacts and human interference with the climate system, incautious implementation of this rule can be accompanied with extra burdens. Drastic emission reductions are justified if climate goals will be affected, but only then.

5. Model results

All results discussed in this section are based on model runs framed by the assumptions as described in section 2 and 3. The equity and emissions trading issue is investigated by variation of the following model parameters:

- point in time at which a complete per capita distribution of emission rights is realized
- share of allocated emission rights which can be sold
- portion of emissions which can be covered by purchased emission rights.

In the following I want to discuss the results of the four variants[2] represented in Table 1.

1. Within the model, the maximum level of emissions rights that a single region can be supplied with is implicitly constrained by the region's maximum emission level and maximum permit sales level. The formerly cannot be increased arbitrarily due to emission baseline restrictions (Eq. 23 in Appendix A) and limits to the speed of emission increases (Eq. 25 in Appendix A) which represent the sluggishness of the energy system infrastructure. The sale of emission rights is restricted due to the limited import capacity on the side of permit purchasers, which in this example are not allowed to credit more than 50% of their emissions by permit imports.
2. I investigated rather extreme variants in order to come up with significant differences. This does not mean that anyone of these variants is more likely to be implemented than variants in between.

Table 1: Model variants

Year in which equal per capita distribution takes full effect	Without trade restrictions	Emission rights purchase and sale is limited to 30%*
2025	**A1**	**A2**
2100	**B1**	**B2**

* consider that sale and purchase are related to a different base

Figure 3 shows the sensitivity of the optimal global emission paths to restriction of the trade in emission permits for the cases A1 and A2. It indicates that the case with trading restrictions results in an emission path that turns around earlier. This is mainly because the shortage of emission rights of Annex-I countries can not sufficiently be compensated by the purchase of emission rights. This shortage increases unless emission reduction starts right from the beginning. However, differences between the emission paths of these two cases are fairly small. They are even smaller between the cases B1 and B2. The whole course of the emission trajectories is dominated by the climate window. In the first periods, the maximum temperature change rate requires early emission reductions. In the later periods, a decrease of the long-term emission volume to below 2 Gt C is required in order to keep the absolute temperature change threshold of 2˚C.

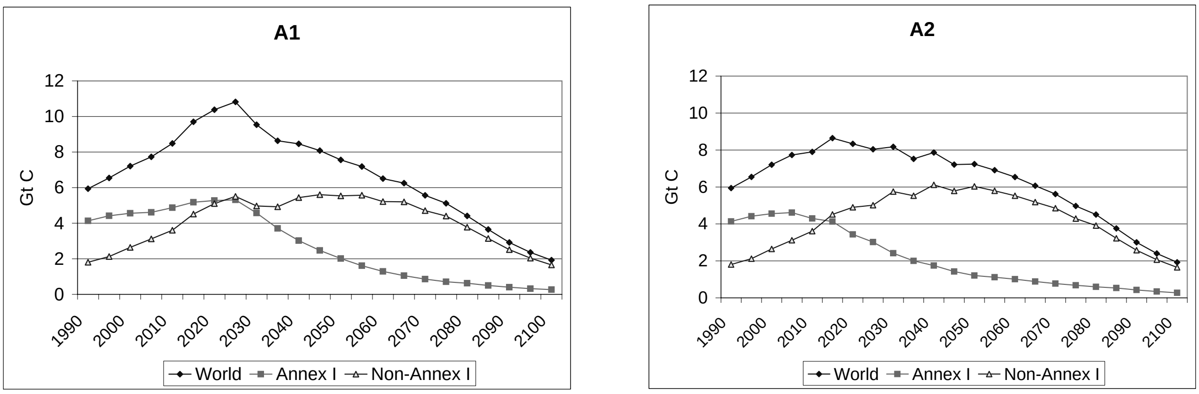

Fig. 3: Carbon dioxide emissions (industrial)

In the following I want to focus on the questions of how the date of complete per capita allocation will alter the burden sharing, and which regions may be affected by trade restrictions. In Figure 4 I demonstrate the changes in per capita consumption in relation to per capita consumption for the reference case for selected regions. There are regions which due the introduction of emissions trading could increase per capita income in comparison to the reference scenario. This is made possible either by the sale of emission rights which cannot immediately be used in an equally productive way, or by creating trade balance deficits (and thus increasing disposable domestic product) in expectation of later opportunities to sell emission rights. The highest gains from emissions trading of more than 10% arise in AFR and SAS if the per capita allocation rule takes effect rather soon. On the other hand this allocation framework generates comparatively high losses of up to more than 3% in CPA, PAS, FSU, MEA and NAM. There is a robust pattern. Regions with high per capita emissions (e.g. FSU, NAM), buoyant economic dynamics (e.g. PAS, CPA) or fossil-fuel dependent economies (e.g. MEA) bear higher costs.

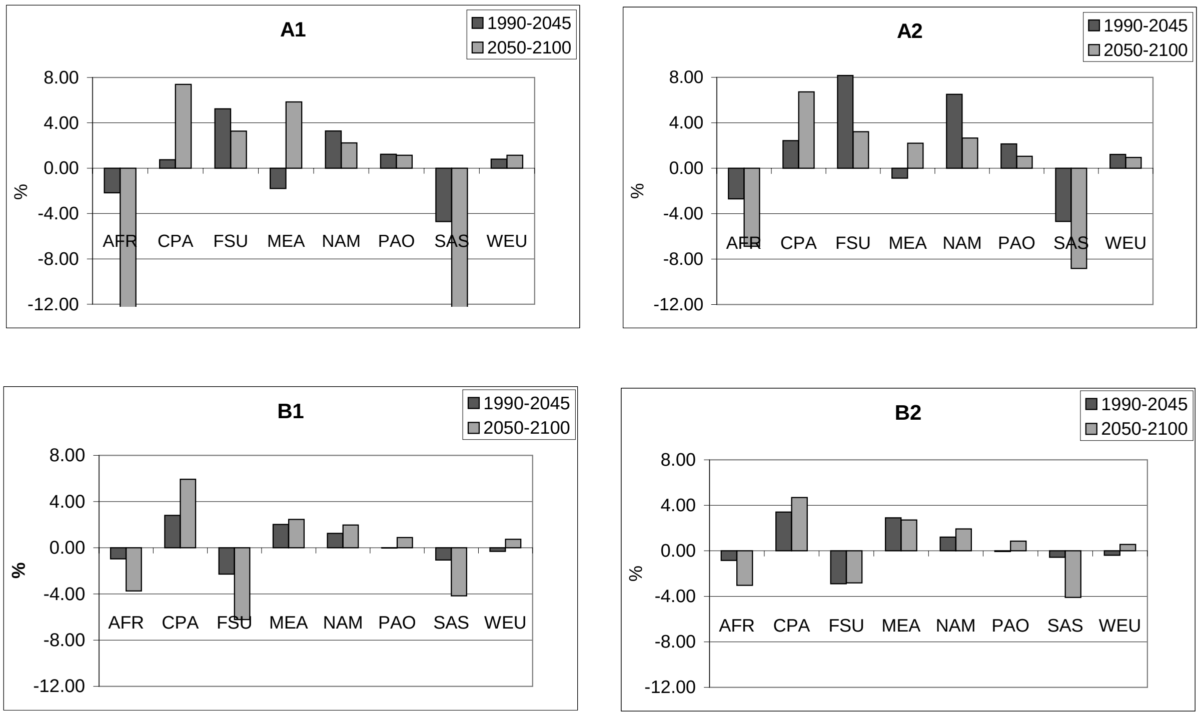

Fig. 4: Loss in per capita consumption (related to reference per capita consumption)

Gains are reduced and losses increased when emissions trading is constrained. While it is in line with the conventional wisdom of economic theory that trade restrictions increase the costs of climate policies[1], this cost-increasing effect is just visible at a second glance at Figure 4. AFR will benefit most from lifting trade restrictions. With a short transition phase to complete equal per capita emission rights allocation this also applies to NAM. In general, benefits from lifting trade restrictions can be demonstrated in the first half of the century, while due to shifts in the terms of trade, losses in the second half of the century become even bigger in the unrestricted cases (e.g. CPA, cases B1 and B2).

While there is a tendency for losses and gains to decline when the transition phase from status quo to equal per capita emission rights allocation is expanded, there are some regions that switch from “losers” to “winners”. This, above all, applies to FSU, which in cases B1 and B2 is provided with a high level of emission rights for a longer time span. This allows FSU to sell emission rights and thereby to improve its terms of trade especially in the early periods. Positive trade balances and improved terms of trade can have a sustained impact on the regional income situation. Thus, although profitable emission rights exports (see Figure 5 for the development of the carbon price within the most and least restricted case) occur mainly before 2050, positive changes in per capita consumption of regions selling emission rights are in general greater in the second half of the 21st century.

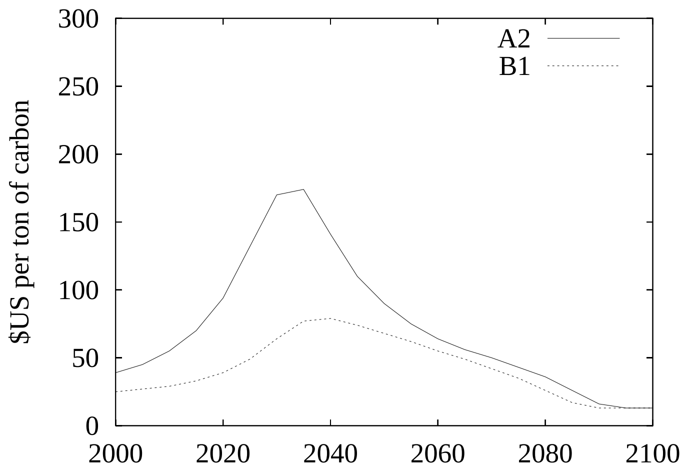

Fig. 5: Carbon price

In the final part of this paper I want to take a closer look at the structure of regional emissions. What amount of emissions is covered either by allocated or purchased emission rights? What amount of emission rights is to be sold? First, Figure 6 shows the absolute volume of trade flows in emission rights. Trading flows are most extensive under the emissions trading regime A1 (around 185 Gt C globally during the whole century). Just half this amount would occur with trade restrictions (ca. 90 Gt C). The grouping of regions as sellers or buyers is quite robust over a range of different model settings. Major sellers are AFR and SAS. Major buyers are CPA and NAM.

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1. It is argued that unconstrained emissions trading does not remove incentives for the industrialized regions to develop energy efficient and carbon free technologies because they could decrease the demand of emission permits and thus save costs. Within the innovation-based approach, however, the superiority of unconstrained trade is challenged. As Porter and van der Linde (1995) argue, innovations are brought about within industrial centers. Reducing the domestic pressure to innovate right in these centers may hinder the development of new technologies. Buonanno et al. (2001) indicate a strong negative correlation between the permit demand and R&D expenditures.

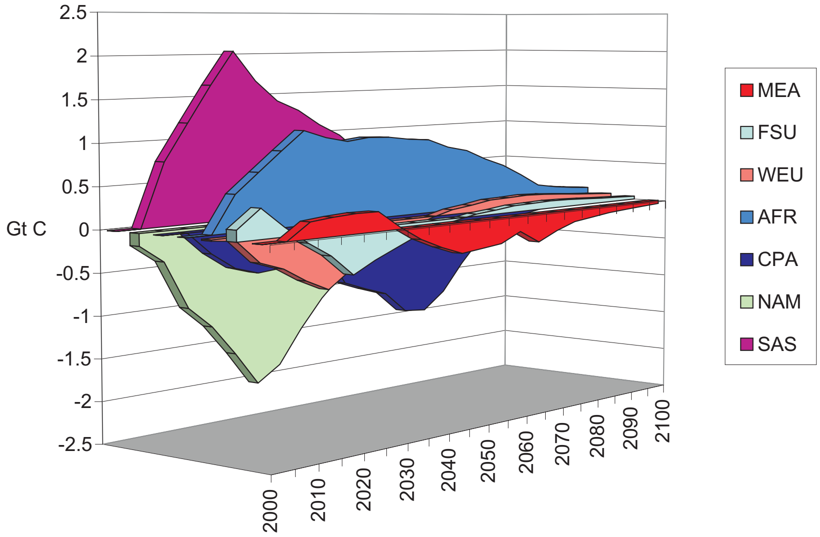

Fig. 6: Emission rights trade (case A1)

Figure 7 shows the impact of emission trade restrictions on the amount of permits purchased by NAM and sold by SAS. Additionally, in Appendix B results are presented on the emission structure and the emission rights use of four major players of future climate policy - CPA, NAM, SAS and WEU. Some insights can be derived for each region:

- In case A2, NAM makes use of the allowed maximum purchase quota in two periods only. Due to sale restrictions there is a temporary excess of demand for emission rights which raises the permit price (see Figure 5). It is cheaper for NAM to reduce domestic emissions rather than to purchase additional permits in most periods. This would result in a fast turnaround of the emission trajectory (see Figure 7). In contrast, a huge amount of permits is purchased in case A1 which allows more time to realize the necessary turnaround of the emission trajectory.
- WEU appears as major purchaser only in the cases A1 and A2. But even in these cases it does not face that amount of costs that NAM is confronted with. The reason is that due to a lower per capita emission level today, WEU is required to perform a comparatively moderate turnaround. Moreover, WEU has the opportunity of equalizing trade balance deficits not just by goods export but also by emission rights export in the second half of the century. In the cases B1 and B2, WEU even become a net seller of emission rights.
- The situation is again contrary for SAS which definitely benefits from the short transition phase towards an equal per capita allocation of emission rights in cases A1 and A2, where the volume of sales is the biggest. If the share on the global pool of permits is increased just slowly for today's low per capita emission regions, than SAS might not just become an emis-

sion rights purchaser, but even a net purchaser over the entire time span (see Appendix B, case B1). The sale of emission rights in the short term is not at the expense of the effective emissions in SAS. Thus, the restriction of emission trade in case A2 does not increase the emission level of SAS (see Figure 7), but implies a portion of dispensable permits[1].

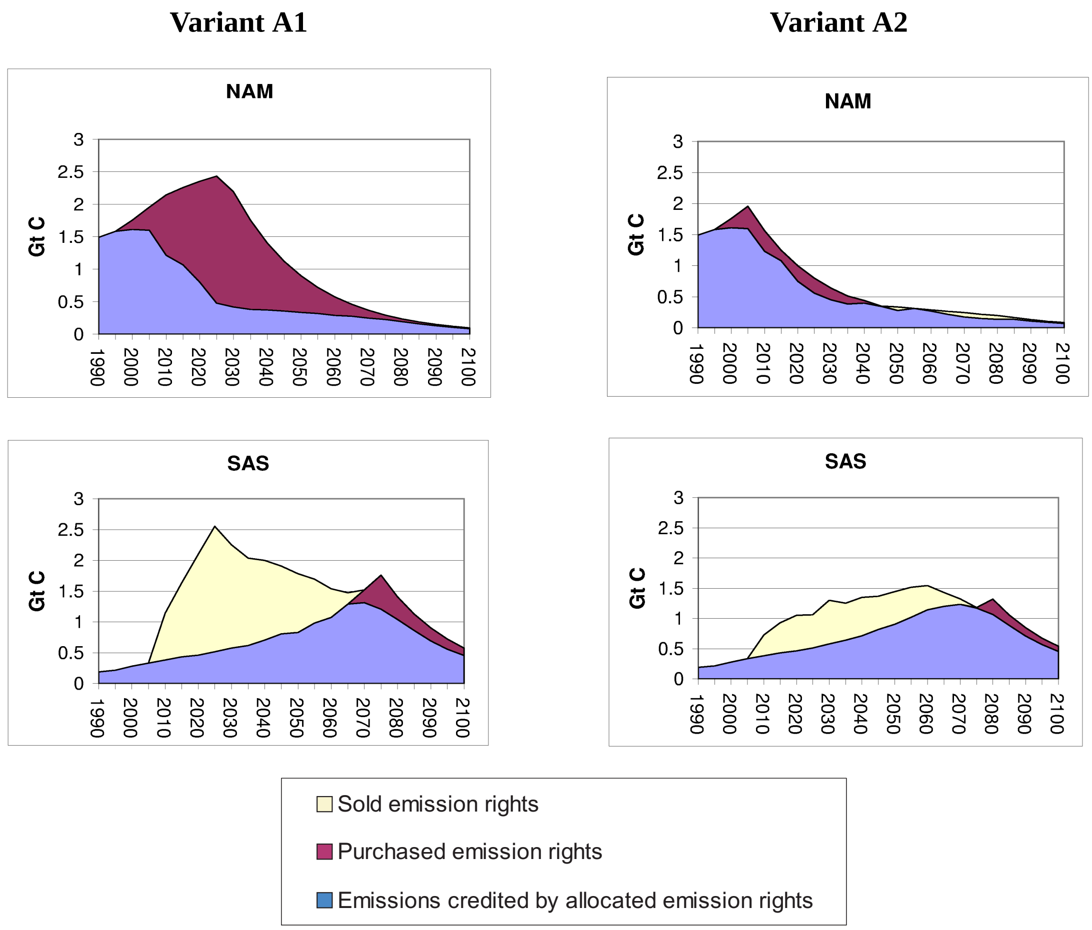

Fig. 7: Emission structure

- For CPA a short transition phase is slightly more beneficial. However, the increase of allocated emission rights is far beyond the increase in emission needs due to dynamic economic growth. Hence, emission rights purchase is necessary in all cases[2].

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1. In cases A1 and A2 low per capita emission regions like SAS receive up to 2025 an amount of emission rights that would allow them to emit above the emission baseline. However, it is assumed that the effective emissions are limited to the business-as-usual baseline level. The emission baseline of the region with the lowest per capita emissions thus determine the per capita emission quota in 2025 in A1 as well as A2. Since the emission rights allocation of A1 and A2 differ only slightly, the trade restriction consequently leads to a considerable amount of emission rights being unused (resulting in a lower peak in the global emission trajectory - see Figure 3).

In addition to different emission structures, the diagrams in Appendix B depict also very different intertemporal emission profiles. While Annex-I regions will reach their maximum level within the coming decades, most of the non-Annex-I regions will continue to increase their emissions for more than 50 years. In developing regions like PAS, CPA and LAM significant emission reductions related to the emission baseline are necessary, however, in the first half of this century.

For most regions an allocation variant with long transition phase is preferable in pure economic terms. Regions that do not benefit from a long transition phase (e.g., AFR and SAS), nevertheless, still benefit in relation to the reference case (see Figure 4). However, if we look at model results from a point of view focussing even more strongly on equity, case A1 is superior. This is indicated in Table 2. The relevant criteria are an equity welfare measure and the ratio between the highest and the lowest regional welfare weight. With welfare weights *nw* and i representing the region index, the latter is defined as:

(1) $RNW = \max_{i} nw_i^{*} : \min_{i} nw_i^{*}$ with nw_i^{*} as part of the equilibrium solution.

The original global welfare variable (see Eq. 1 in Appendix A) aggregates regional utilities by means of the welfare weights. The welfare weights themselves serve as adjustable parameters that help to find an equilibrium solution (see Leimbach and Toth, 2003). Negishi (1972) proved that such an equilibrium exists, in which case the weights are identical to the inverse of the marginal utility of income of regions. According to Manne and Rutherford (1994) the equilibrium value of the weights may also be interpreted as the share each region has in global wealth accumulated over the entire time horizon (present value of global resource endowment). With this interpretation, the meaning of the second equity criteria in Table 2 is straight forward. Since the sum of the welfare weights is kept constant, it follows that the higher *RNW*, the more unequally global wealth is distributed[1].

The equity welfare measure (*EWF*) is based on a reevaluation of the optimal solution (i.e. of the regional utilities U_i^{*}). This is done by equalizing the welfare weights:

(2) $EWF = \Sigma_{i} (nw_i * U_i^{*})$ with $nw_i=1$, and U_i^{*} as part of the optimal solution.

While this does not change the solution (and does not require new optimization runs), it makes the different cases comparable with respect to welfare[2]. Higher values are superior.

2. The little dent that occurs with the emission trajectories of CPA is not an equity dent. It is a temporary decline of the emission path that is caused by the temperature change rate threshold of 0.2 degree Celsius per decade.
1. This equity interpretation is in line with the Rawlsian justice (Rawls, 1971) according to which decisions should be taken so as to consider the least fortunate or well-off.
2. The present variants A1-B2 yield different solutions. Part of each solution is a particular set of welfare weights, which imply a scaling, that normally prevents comparison of the welfare measures.

Table 2: Equity Criteria

Variant	Equity Welfare (EWF)	Ratio between maximum and minimum regional welfare weight (RNW)
A1	1784.38	18.07
A2	1779.70	21.94
B1	1775.31	33.47
B2	1773.40	34.63

Here, I just look at interregional equity. Buonanno et al. (2001) apply an equity index, following Bosello and Roson (2000), which is also suited to compare intergenerational equity. The present results demonstrate that an emissions trading regime that quickly transits from status quo to equal per capita emission rights allocation is the most fair. Simultaneously, under the analyzed model setting unrestricted emissions trading is more useful in finding more equitable solutions than regimes with trade restrictions. The latter confirms the results of Buonanno et al. (2001) who did not take terms of trade effects into account.

6. Conclusions

I analyzed equity aspects of an emissions trading regime that should help to meet long-term climate goals. The chosen climate window which restrict temperature change to 0.2 degrees Celsius per decade and 2 degrees Celsius over the entire time horizon requires considerable mitigation efforts. Hence, the mitigation costs are somewhat higher than in many other model studies and most comparable with 450 ppm stabilization scenarios (cf. Manne and Richels, 1995).

In model experiments I varied the transition time from status quo to equal per capita emission rights allocation. All model runs rely on constrained welfare maximization. While in the case of unrestricted trade, the variation of the allocation rule only affects the distribution of mitigation costs but not the regional and global emission reduction paths, with trade restrictions the latter are affected too. This is although there are only minor differences in the allocation of emission rights between the restricted and the unrestricted cases. The main results can be divided up between those that are intuitively obvious:

- long transition phases between status quo and equal per capita allocation of emission rights are less costly,
- trade restrictions require stronger reduction efforts in industrial countries in the short-term,

and those that are either new or the subject of controversial scientific debate:

- short transition phases between status quo and equal per capita allocation of emission rights are more equitable,
- unrestricted trade is superior from an economic and equity point of view,
- trade restrictions may cause a considerable amount of emission rights to remain unused,
- emissions trading can significantly change the terms of trade,
- imprudently combining equal per capita allocation and trade restrictions, distorts fairness and efficiency (equity dent),
- CPA (i.e. China) might become a competitor on the permit market, demanding a huge amount of emission rights.

The most important implication with respect to future climate policy can be seen in the potential benefits that several developing countries (e.g. India) may gain from an international emissions trading regime. This of course depends on the general conditions and the specific implementation of such a regime, which includes more than simply deciding how to allocate emission rights. However, a fair distribution of emission rights is likely to provide impetus to international climate policy negotiations, with the advantage that non-Annex-I countries could be involved.

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Appendix A - Technical description of the aggregated economic model

(1)	$W = \Sigma_i (nw_i * U_i)$	
(2)	$U_i = \Sigma_t (POP_{it} * e^{-\rho t} * \log(c_{it}))$,	i=1,...,n.
(3)	$Y_{it} = A_{it} * K_{it}^{\alpha it} * POP^{(1-\alpha it)}$,	i=1,...,n , t=1,...,T.
(4)	$NY_{it} = Y_{it} - (GPLO_{it} - GPLO_{i,t-1}) + dum_{it}$,	i=1,...,n , t=1,...,T.
(5a)	$dum_{it} = 0$ if $GPLO_{it}-GPLO_{i,t-1} > 0$,	i=1,...,n , t=2,...,T,
(5b)	$dum_{it} = GPLO_{i,t-1}-GPLO_{it}$ if $GPLO_{it}-GPLO_{i,t-1} < 0$,	i=1,...,n , t=2,...,T.
(6)	$GPLO_{it} = \Sigma_{\tau \leq t} Y_{i\tau} * DCR_{ijt}$,	i=1,...,n , j=”CO2”, t=1,...,T.
(7)	$DCR_{ijt} = b1_{ijt} * \mu_{ijt}^{b2ij}$,	i=1,...,n , j=”CO2”, t=1,...,T.
(8)	$\mu_{ijt} = \Sigma_{\tau \leq t}(BEM_{ij\tau} - EM_{ij\tau}) / \Sigma_{\tau \leq t} BEM_{ij\tau}$,	i=1,...,n , j=”CO2”, t=1,...,T.
(9)	$C_{it} = NY_{it} - I_{it} - CA_{it} - NTX_{ikt}$,	i=1,...,n , k=1, t=1,...,T.
(10)	$\Sigma_i NTX_{ikt} = 0$,	k=1, 2, t=1,...,T.
(11)	$NTX_{ikt} \leq xperm * SH_{it} * GLR_t$,	i=1,...,n , k=2, t=1,...,T.
(12)	$-NTX_{ikt} \leq mperm * EM_{ijt}$,	i=1,...,n , k=2, t=1,...,T.
(13)	$K_{it} = (1-\delta_{it}) * K_{i,t-1} + I_{i,t-1}$,	i=1,...,n , t=1,...,T.
(14)	$I_{it} \leq inup * I_{i,t-1}$,	i=1,...,n , t=1,...,T.
(15)	$\Sigma_i CA_{it} = 0$,	t=1,...,T.
(16)	$NFA_{it} = (1 + RR_{t-1}) * NFA_{i,t-1} + CA_{it}$,	i=1,...,n , t=1,...,T.
(17)	$RR_t = \Sigma_i ((\alpha_{it} * Y_{it})/K_{it} - \delta_{it})/n$,	t=1,...,T.
(18)	$NFA_{iT} = 0$,	i=1,...,n.
(19a)	$NTX_{ikt} + CA_{it} \leq expo * Y_{it}$,	i=1,...,n , t=1,...,T.
(19b)	$-NTX_{ikt} - CA_{it} \leq impo * Y_{it}$,	i=1,...,n , t=1,...,T.
(20a)	$NFA_{it} \leq fmax * Y_{it}$,	i=1,...,n , t=1,...,T.
(20b)	$-NFA_{it} \leq fmin * Y_{it}$,	i=1,...,n , t=1,...,T.
(21)	$c_{it} = C_{it}/POP_{it}$,	i=1,...,n , t=1,...,T.
(22)	$EM_{ijt} \leq SH_{it} * GLR_t - NTX_{ikt}$,	i=1,...,n , j=”CO2”, k=2, t=1,...,T.
(23)	$EM_{ijt} \leq BEM_{ijt}$,	i=1,...,n , j=”CO2”, t=1,...,T.
(24)	$\Sigma_i EM_{ijt} \leq GLR_t$,	j=”CO2”, t=1,...,T.
(25)	$\lvert 1 - EM_{ijt} / EM_{ij,t-1} \rvert \leq err$,	i=1,...,n , j=”CO2”, t=1,...,T.
(26)	$E_t = GLR_t + LUEM_{jt}$	j=”CO2”, t=1,...,T.
(27)	$SH_{it} = PSH_i$,	t=LQ,...,T.
(28)	$SH_{it} = ((LQ-t) * SH_{i,0} + (t-1) * PSH_i)/(LQ-1)$,	t=1,...,LQ-1.

Indices:

i	-	regions,	k	-	traded goods (1 = composite good; 2 = emission permits),
j	-	greenhouse gases,	t,τ	-	time index.

Endogenous variables:

W - global welfare,
U - regional welfare,
Y - gross product,
C - consumption,
c - per capita consumption,
NY - disposable gross product,
K - capital stock,
I - investments,
GPLO - cumulative GDP losses,
dum - auxiliary variable,
DCR - cumulative emission reduction (percentage GDP),
μ - cumulative emission reduction rate (related to baseline emission),
NTX - net exports,
RR - net rate of return on capital,
CA - capital transfer (FDI),
NFA - net foreign assets,
EM - regional CO_2 emissions,
E - total CO_2 emissions,
GLR - global permits for industrial CO_2 emissions,
SH - share on global emission rights.

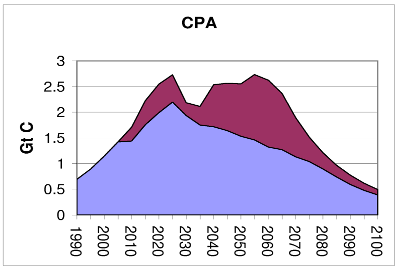
Parameters and exogenous variables:

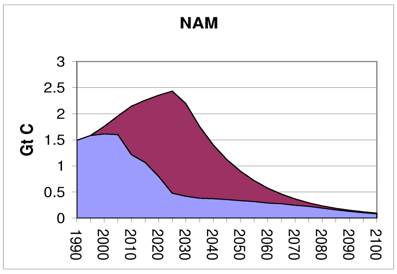
POP - population,
A - total factor productivity,
BEM - industrial CO_2 baseline emission,
LUEM - land use emissions,
PSH - share on global population in 2025,
ρ - pure rate of time preference,
nw - welfare weights (endogenous within the master optimization problem),
b1, b2 - parameter of abatement cost function,
α - output elasticity of capital,
β - output elasticity of labor,
δ - depreciation rate,
n - number of regions,
inup - maximum investment rate,
expo - maximum share of capital transfers and exports on GDP,
impo - maximum share of imports on GDP,
xperm - maximum share of allocated emission rights allowed to be exported,
mperm - maximum share on emissions credited by emission rights import,
fmax - maximum share of net foreign assets on GDP,
fmin - maximum share of net foreign debts on GDP,
err - maximum rate of emission reduction (related to previous period),
LQ - period of complete equal per capita emission rights allocation,
SH_0 - status quo emission share.

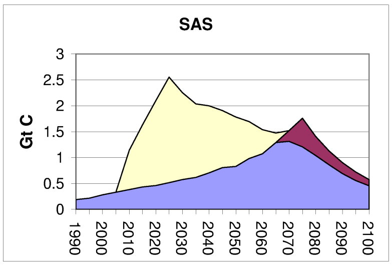
Appendix B - Emission Structure

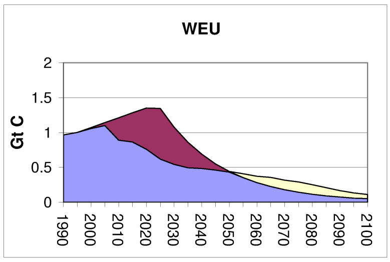
- Sold emission rights
- Purchased emission rights
- Emissions credited by allocated emission rights

Variant A1









Variant B1