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Summary of Final Report

Scenarios for the Regional Distribution of Long-term Emission Rights and Impacts of Climate Change

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SUMMARY

Global climate change is currently discussed from two main perspectives:

- One being on the extent and costs of mitigation measures (including the question where and how emission cuts can be realized most cost-effectively);
- the other being on the adverse impacts of climate change and how to adapt to these mostly negative effects (including the question how to finance an adaptation to changed climate conditions).

The main objective of this study is to combine these two perspectives so that, hopefully, a mutual understanding of the different views on the problem of climate change and its mitigation might support the process of climate negotiations. The study is, therefore, divided into two parts:

- In the first part, an allocation scheme for future regional emission rights between 1990 and 2100 is presented which has a clear focus on reaching long-term climate targets. An application of this scheme yields the amount of emissions saved that each of 17 world regions contributes to the achievement of a stabilization target.
- In the second part, a model-based assessment of the effects of changing temperature and precipitation on global water availability and agricultural production is presented. This assessment provides the extent of climate change impacts that each of the regions might have to bear in the future under two different emission scenarios.

As a result of this analysis, a possible long-term contribution of a region to achieve a climate target can be seen in relation to the impacts that this region might bear under changing climate conditions.

The new IPCC scenarios

All analyses of this report are based on two scenarios of the Intergovernmental Panel on Climate Change (IPCC), namely the so-called A2 and B2 scenario. The world of the A2 scenario is characterized by a regional heterogeneous development in which economic growth and technological changes are slow and the population is constantly increasing. The world of the B2 scenario aims at sustainable development but with solutions differing from region to region. This results in an intermediate growth of the global economy and a technological change which is faster than in the A2 world. The global population shows an increasing tendency but at a lower rate than under the A2 scenario. These different developments result in a wide range of global greenhouse gas emissions by the end of the century: Under the A2 scenario, emissions are increasing by a factor of four between 1990 and 2100 whereas under the B2 scenario, emissions “only” double between now and 2100 (i.e. they are half of the A2 emissions in 2100).

ALLOCATION OF EMISSION PERMITS

Based on the socio-economic development of the A2 und the B2 scenario as implemented in the IMAGE 2.2 model (**I**ntegrated **M**odel to **A**ssess the **G**lobal **E**nvironment), an alloca-

tion scheme is described for 17 world regions. This scheme emphasizes a long-term perspective as it is necessary to realize a stabilization of the greenhouse gas concentration in the atmosphere. The allocation scheme consists of three simple rules:

Rule No. 1: Per capita emissions of all Non-Annex B regions may follow their reference emissions until an average income level is reached which enables a region to start mitigation measures (graduation income). The first measure is a stabilization of per capita emissions, the second one a decrease of per capita emissions. This decrease starts when per capita emissions of a Non-Annex B region become equal to the average of Annex B per capita emissions.

Rule No. 2: For each year a globally allowable amount of greenhouse gas emissions must be prescribed, e.g. derived from an emission pathway which allows to achieve a stabilization of greenhouse gas concentrations in the long-term.

Rule No. 3: Annex B regions must start emission controls immediately. Their total emissions result from the difference between global emissions from Rule No. 2 and total emissions of all Non-Annex B regions calculated from the results of Rule No. 1.

Starting with the regional reference emissions of the IMAGE A2 and B2 scenarios different pathways for future regional CO_2-equivalent emissions are described which allow to reach a greenhouse gas stabilization at 450 or 550 ppm CO_2 in the atmosphere, respectively.

Per capita emissions and the beginning of mitigation measures

In order to achieve a stabilization at 450 ppm CO_2 in the atmosphere, a global average of per capita emissions is allowed at the end of the century between 20% (basis A2 scenario) and 29% (basis B2 scenario) of current per capita emissions (1.3 t C-equivalents per person). A stabilization target of 550 ppm CO_2 requires a long-term decrease to 45% of current per capita emissions under the A2 scenario and to 64% of current emissions under the B2 scenario. These numbers make clear that, regardless of the stabilization target and the base scenario, the global average of per capita emissions must sink below one ton C-equivalents per person in the long-term.

In order to reach this level of per capita emissions, Annex B regions must, depending on the scenario assumptions and the stabilization target, decrease their emissions to 5-22% of their present emissions until 2100. Another consequence of the different scenario assumptions is that a 50% cut of emissions per inhabitant must be realized between 2025 and 2050 at the latest.

Non-Annex B regions begin to participate in a climate protection regime by first stabilizing and then decreasing their per capita emissions. They will participate earlier (1) the faster their income reaches a prescribed graduation level (which must be negotiated), (2) the faster their per capita emissions come closer to (decreasing) Annex B per capita emissions and (3) the stricter the climate protection target to be achieved (which must still be negotiated).

The point in time when Non-Annex B regions begin to participate in a climate protection regime will be between “immediately” (1990)[1] and 2080 if the graduation income is low. Low income in this scenario means that it is equal to the income of the poorest Annex B region in 1990. Non-Annex B regions will start with climate protection measures between 2020 and 2100 or even later if a high graduation income is chosen. High income in this context means an income which is equal to the average income of all Annex B regions in 1990. In the case of early measures (or a low graduation income), maximum per capita emissions of nine out of ten Non-Annex B regions may never exceed 1.2 t C-equivalent. Late measures or a high graduation income allow a maximum per capita emission which, depending on the region, lies between 0.4 and 2.5 t C-equivalents per person.

Total emissions

The maximum amount of greenhouse gases that a Non-Annex B region may emit per year depends on its current per capita emissions and its economic strength. As a consequence of the fairness principles of the allocation scheme, the Non-Annex B region with the lowest income and the lowest per capita emissions (East Africa) may increase its current emissions by a factor of 30 if the climate target is 450 ppm CO_2 under the B2 scenario, and by a factor of 47 if the climate target is 550 ppm and the graduation income is high. At the other end of the spectrum, the Non-Annex B region with currently the highest average income (South America) may increase its total emissions by a maximum factor of 2 under a strict climate target of 450 ppm CO_2 combined with a low graduation income, and by a factor of 6 under the 550 ppm target combined with a high graduation income. At the end of the century, however, total emissions of all Non-Annex B regions together may only increase by a factor of 1.6 to 3.3 compared to current emissions. Based on the IPCC scenarios, the population of these regions increases at a similar speed – by a factor of 2.3 to 3.2 between 1990 and 2100.

The total emissions of the Annex B regions decrease under all scenarios. They must cut them down by 50% in 2025 at the latest under the B2 scenario with a stabilization target of 450 ppm CO_2 and late participation of the Non-Annex B regions. The halving of total emissions may be postponed to 2085 if the world develops as described for the B2 scenario, but aims at a stabilization target of 550 ppm CO_2, and Non-Annex B region’s participation in a climate protection regime happens quite early because of a low graduation income. However, until 2100 Annex B emissions must be decreased under all scenarios so that they reach between 10 and 26% of the current emissions.

[1] In this study we have a strict focus on the long-term influence of the allocation scheme on regional emissions. It can therefore happen that the results partly conflict with current climate policy targets such as the Kyoto Protocol. For reasons of transparency we present the results of the approach without corrections which can easily be included in a further step.

Accumulated emissions

The difference between the accumulated reference emissions of a region and the accumulated emissions of a climate protection scenario of that region allows us to make a statement about this region's contribution to achieve a climate protection target.

All Annex B regions together may emit between 32% and 100% of their accumulated reference emissions. The first value is valid in an A2 world which aims at a 450 ppm CO_2 stabilization target and in which Non-Annex B regions begin to participate late because of a high graduation income. If, however, a B2 world aims at a CO_2 stabilization at 550 ppm and Non-Annex B regions start early with climate protection measures, it might happen that Annex B emissions never depart from the reference emissions pathway because they already show a decreasing tendency under the B2 scenario without any climate protection measures.

The contribution of the Non-Annex B regions to achieve a global climate target varies strongly from region to region. Depending on their future reference emissions, the rules of the allocation scheme and the strictness of the climate target, the regions of the Non-Annex B group may emit between 26% and 100% of their accumulated reference emissions between 1990 and 2100. Especially, a low graduation income combined with a strict climate target requires a saving of emissions which is comparable to that of the Annex B regions. Two to three regions out of ten, however, might be freed from any measures because of their very low income and per capita emissions. This is only the case if the climate target is set at 550 ppm CO_2 and the graduation income is high. Otherwise, these regions must also reduce their emissions - but late in the century.

CLIMATE IMPACT ASSESSMENT

In the climate impact assessment, we investigate the changes to two essential resources for human life, namely the global water supply and the agricultural productivity. We use two global models to perform these assessments which represent the state of the art of large scale modelling of global change in the water sector (Water – **G**lobal **A**ssessment and **P**rognosis; WaterGAP 2.1) and the agricultural sector (**G**lobal **A**gro-**E**cological **Z**ones model; GAEZ). Again the long-term impacts of the IPCC A2 and B2 scenarios have been evaluated.

Global climate change

For the impact assessment we used temperature change and change of precipitation as input for the two models. Global temperature change between the climate normal period (1961-1990) and the 2070s was obtained from the general circulation model (GCM) HadCM3. Annual climate variability was considered by adding the annual variability of the historical 30-year period 1961-1990 to the mean change of temperature and precipitation of the GCM.

The mean global temperature change in the 2070s period as calculated by the HadCM3-model will be about 2.2°C under the B2 scenario and about 2.8°C under the A2 scenario. The climate sensitivity of the HadCM3 is 3°C for a doubling of the CO_2 concentration. Spatial patterns of precipitation change are very heterogeneous, with a strong increase of precipitation in the northern latitudes and a decrease of precipitation especially in the Mediterranean area.

Change of the global water situation

Both, a change of precipitation and a temperature increase will affect the future availability of water. Whether or not, however the water supply of a country's population will be threatened, also depends on the development of the water demand of this population. We therefore present the future water availability as well as the water demand as calculated by the WaterGAP-model.

Water availability

On the global level, the water availability will rise under changing climate conditions because a temperature increase leads to increasing water evaporation from the oceans. As a consequence, under the A2 scenario with its higher temperature increase, more water is available in the atmosphere than under the B2 scenario. However, the change in availability is distributed regionally very unevenly - comparable to the change in precipitation as the most important factor of a climate-induced change of water availability.

Water use

The future of global water use might differ substantially, depending on underlying scenario assumptions. Under the A2 scenario, water use will increase throughout the century due to increasing population and economic growth. Consequently, in 2075 water use will be 155% of the water use in 1995. Under the B2 scenario, the global population is growing at a lower rate but the per capita income is growing faster than under the A2 scenario. Since the B2 world is a more ecologically oriented world, it is assumed that the water use efficiency is increasing much faster than under the A2 scenario. As a consequence of all these assumptions, water use is continually decreasing under this scenario: water use in 2025 will be at 95% of the 1995 value and in 2075 it will reach 78% of the current value.

Water stress

As an indicator for the criticality of the future water situation, we use the ratio of water withdrawal to water availability (w.t.a.). If more than 40% of the available water is withdrawn from a river, a lake or the groundwater (w.t.a. > 0.4), we define it as a situation of high water stress. According to this definition, there was already high water stress during the 1990s in many countries around the Mediterranean Sea, in the Middle East and in some parts of Northern China. This was also the case for the South of Africa and the West of the North- and South American Continent.

Under the A2 scenario, in some of these region, especially in the North and East of the African continent, water stress will increase. Additionally, in some regions, e.g. in the Northeast of Brazil, regions with water stress will grow due to a combination of decreasing precipitation and increasing water use.

Under the B2 scenario, there will be an improvement in the water situation in some regions compared to the A2 scenario. This is the case for the North and the East of Africa but also for Eastern Europe. But there are also regions where the situation will get worse compared to the A2 scenario, as for example in the South of India. Since under the B2 scenario the change of water use in most regions is negligible, a change of criticality is mostly caused by a changing climate or more precisely, a change in precipitation.

Frequency of extreme runoff events

An extreme runoff event is defined here as the combined change of the coefficient of variation of runoff and the mean change in precipitation. Under the A2 scenario as well as under the B2 scenario, the frequency of extreme runoff events will increase. There are some areas under the B2 scenario which will be affected less by more frequent extremes compared to the A2 scenario. Since there are also areas where the extremes are more frequent under the B2 scenario compared to the A2 scenario, we cannot clearly state whether or not the lower level of greenhouse gas emissions under the B2 scenario will affect the frequency of extreme runoff events.

Change of agricultural productivity

From the global perspective the climate-induced change of the potential agricultural productivity may be very similar under the A2 and the B2 scenario. In the medium-term (2020s), the productivity (in terms of caloric production) decreases by 7% under the A2 scenario and by 6% under the B2 scenario. In the long-term (2070s), the productivity under the B2 scenario decreases by 17% which is still similar to the A2 scenario (-20%) although greenhouse gas emissions are only half that of the A2 scenario at the end of the century. Under both scenarios, half of all countries worldwide will be affected by a decrease in agricultural productivity of 10% or more.

In the medium-term, the Non-Annex B regions might have to bear stronger climate-induced decreases in productivity than the Annex B regions. Although greenhouse gas emissions under both scenarios are similar in the 2020s, the lower SO_2 emissions of the B2 scenario might induce a stronger climate change in the Southern hemisphere at that point in time.

In the long-term, the lower emissions of the B2 scenario are more advantageous for the Annex B regions than for the Non-Annex B regions. Agricultural systems in the Non-Annex B regions are more sensitive to small changes in temperature and precipitation since their current agricultural areas currently can often be found in areas that do not have optimal growing conditions. For the Non-Annex B regions, long-term changes in productivity are therefore very similar under the A2 and the B2 scenario.

An optimisation of crops (in terms of crop selection) under future climate conditions can theoretically lead to an increase in global productivity by about one third. The potential for an increase in productivity are higher in the Non-Annex B regions – however, problems might remain because the increase in the population in these regions might be higher than the increase in potential productivity by an optimisation of crop types.

The frequency of crop failure is defined here as the number of years per decade when the potential productivity is 50% or lower than the current mean productivity. Under the A2 scenario, the frequency of these events might double or even triple in the countries around the Mediterranean Sea and in the South of the African continent because there might be more dry runoff extremes in the future. Under the B2 scenario, in about half of the countries that will see an increased frequency in crop failure under the A2 scenario, crop failures will be less frequent than under the A2 scenario; in the other 50% of the countries, however, the frequency of crop failures will be comparable to that of the A2 scenario or ever higher.

CONCLUSIONS

The following conclusions can be drawn from these analyses:

1. In order to achieve a long-term stabilization of greenhouse gas concentrations, the global average per capita emissions must decrease to a level below one ton C-equivalents per person. If climate policy aims for a convergence of per capita emissions under the given rules mainly the Annex B regions but also many of the Non-Annex B regions will have to avoid a large share of their future emissions and will thus contribute substantially to achieve a stabilization target (see Table 1).
2. A combined analysis of the allocation scenarios and the climate impacts presented in this report indicates that particularly regions having an income around the average income of the Non-Annex B group might be burdened twice. It is expected that they start to participate in a climate protection regime relatively soon. In addition to this restriction of their emission rights, they will have to tolerate considerable consequences of changing climate conditions (see Table 1). As shown in earlier studies, the rise of greenhouse gas emissions in the last 30-40 years will lead to a considerable and unavoidable change in temperature and precipitation in the coming decades. These facts should be considered when the timing and extent of participation of Non-Annex B countries in a climate protection regime are being negotiated.
3. However, if Non-Annex B emissions rise too much, the consequence may be that the rate and extent of emission reductions of the Annex B regions will become simply unrealistic. In this situation, a crucial point in future climate negotiations will probably be (or remain) the future design of the flexibility mechanisms of the Kyoto Protocol. In contrast to the current situation, however, the further development of these mechanisms should predominantly focus on the long-term perspective. An important question here

is, for example, how the linkage between different flexibility mechanisms such as the clean development mechanism and emission trading can be designed in a way that it induces the development and introduction of new more efficient (carbon-free) energy technologies in the industrialized countries in the *short-term* so that these technologies are available in the poorer regions of the world in the *mid- to long term* thus allowing a sustainable energy production without a multiplying of future greenhouse gas emissions in these regions.

Table 1 Regional CO_2 emissions to achieve a stabilization of the atmospheric CO_2 concentration at 550 and 450 ppm, respectively, climate-induced change of the potential agricultural productivity and change of water availability under the IPCC SRES scenarios A2 and B2.

REGION	**EMISSION MITIGATION**								**CLIMATE CHANGE IMPACTS**			
	Stab. 550 ppm CO_2				**Stab. 450 ppm CO_2**				**Δ Agricult. produktivity**		**Δ Water availabilty [2)]**	
	Start of measures [year]		Δ Cum. emissions [% of reference em.]		Start of measures [year]		Δ Cum. emissions [% of reference em.]		Range A2 - B2 [% of 1961-90 productivity]		A2 and B2 [change relative to 1961-90]	
	Scenario A2-high	B2-low	A2-high	B2-low	**Scenario** A2-high	B2-low	A2-high	B2-low	**2020s**	**2070s**	**A2 - 2070s**	**B2 - 2070s**
Annex B												
Former USSR	1990	1990	44 [1)]	100	1990	1990	32	59	94 - 95	86 - 85	↗	↗
Japan	1990	1990	44	100	1990	1990	32	59	105 - 104	104 - 104	↗	→
Canada	1990	1990	44	100	1990	1990	32	59	105 - 108	96 - 104	↗	↗
OECD Europe	1990	1990	44	100	1990	1990	32	59	95 - 93	77 - 85	↘	→
Eastern Europe	1990	1990	44	100	1990	1990	32	59	95 - 92	73 - 79	→	→
Oceania	1990	1990	44	100	1990	1990	32	59	97 - 89	87 - 88	→	↘
USA	1990	1990	44	100	1990	1990	32	59	85 - 90	71 - 79	↘	→
Non-Annex B												
Central America	2040	2000	57	71	2030	2000	40	58	91 - 93	80 - 78	↘	↘
Middle East	2030	1990	44	57	2020	1990	30	38	100 - 89	87 - 96	→	↘
Northern Africa	2040	2020	60	83	2030	2020	40	61	104 - 97	64 - 66	↘	↘
Eastern Africa	> 2100	2070	100	87	2075	2070	92	87	102 - 100	94 - 97	↗	↗
East Asia	2045	2005	68	69	2035	2005	49	58	89 - 94	80 - 79	↗	→
South America	2035	1990	62	48	2025	1990	43	44	90 - 96	77 - 79	↘	↘
Southern Asia	2060	2030	88	100	2045	2030	63	83	108 - 92	82 - 80	↗	→
Southern Africa	2045	2035	59	84	2035	2035	41	67	90 - 85	77 - 75	↘	↘
Southeast Asia	2060	2010	80	66	2035	2010	58	61	95 - 96	90 - 91	→	→
Western Africa	>2100	2065	100	92	2070	2065	89	92	100 - 101	94 - 97	→	→
World			**58**	**85**			**42**	**61**	**93 - 94**	**80 - 83**	↗	↗

[1)] For the distribution of future emission rights the Annex B regions were treated as one group which results in the same percentage of cumulated emission allowances. The change in cumulated CO_2 emissions represents the largest range of cumulated Annex B emissions between 1990 and 2100.

[2)] The change in water availability was calculated on the basis of watersheds which often belong to more than one region. It was therefore not possible to regionally quantify the changes. Consequently, we analysed the changes visually. → means that in the future there will be no changes of water availabilty in the watersheds within a region or there will be as much watersheds with increasing water availabilty as watersheds with decreasing water availability. ↗ means that the water availability in most watersheds within a region will increase. ↘ means that the water availabilty in most watersheds within a region will decrease.