ANALYSIS OF POST-2012 CLIMATE POLICY REGIMES

Marian Leimbach[1], Nico Bauer, Lavinia Baumstark

[1]PIK - Potsdam Institute for Climate Impact Research, P.O. Box 60 12 03, D-14412 Potsdam, Germany, Tel. ++49/331/288-2556, e-mail: leimbach@pik-potsdam.de

1 Introduction

It is the objective of the UN Framework Convention on Climate Change to stabilise the concentration of greenhouse gases on such a level that ”would prevent dangerous anthropogenic interference with the climate system” (article 2 of the Framework Convention on Climate Change). This objective is an essential basis for the international negotiation process to further develop the climate regime (Kyoto Protocol and follow-up agreements). Based on the EU target to avoid a warming of the Earth’s atmosphere by more than 2°C compared to the pre-industrial level, this study aims to identify the magnitude of costs to attain such a climate protection target under different constellations of the post-2012 climate regime. The regional specification of mitigation costs is analysed in the context of globalisation where regions are linked by different global markets for emission permits, goods and resources.

The newly-developed model REMIND-R serves as the basic tool. REMIND-R is a multi-regional hybrid model which couples an economic growth model with a detailed energy system model (see Figure 1) and a simple climate model. The individual regions are coupled by means of a trade module.

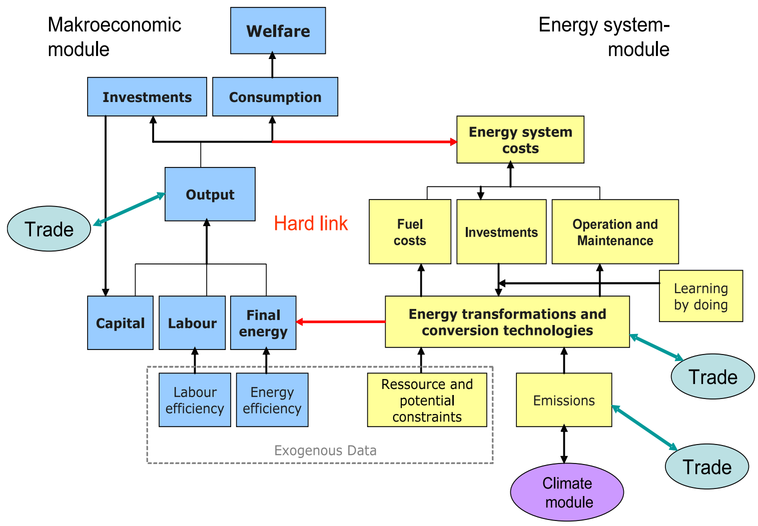


Figure 1: Structure of REMIND-R

The current version of REMIND-R includes nine world regions:

1. UCA - USA, Canada, Australia
2. EUR - EU27
3. JAP - Japan
4. CHN - China
5. IND - India
6. RUS - Russia
7. AFR - Sub-Saharian Africa (incl. Republic of South Africa)
8. MEA - Middle East and North Africa
9. ROW - Rest of the World (including Latin America, Pacific Asia and Rest of Europe).

Each region is modelled as a representative household with a utility function that depends upon the per capita consumption. It is the target of REMIND-R to maximise a global welfare function that results as a weighted sum of the regional utility functions. REMIND-R is run in the cost-effectiveness mode when it is used for climate policy simulations, i.e. climate policy targets are integrated into the model by an additional constraint.

2 Reference scenario

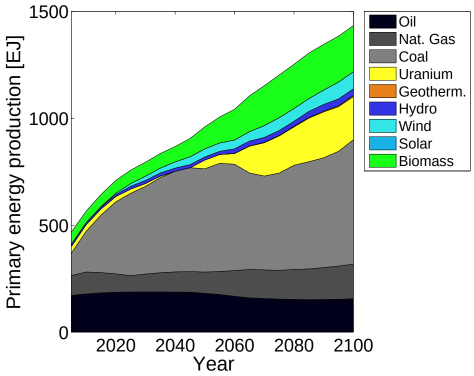
We start the presentation of the results of the model runs with REMIND-R with a discussion of the reference development ("business-as-usual"-scenario). In this scenario, it is assumed that climate change has no economically and socially important effects. Thus, a further world-wide increase of emissions can be assumed. A large part of the economic growth is based on the use of fossil energy sources. This reference development shall serve as a benchmark for scenarios in which climate change is sustainably confronted by climate policy.

2.1 Technology development and energy production

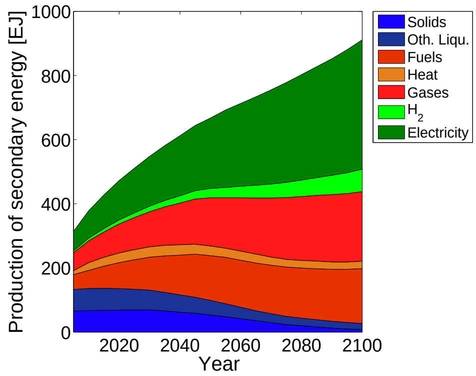
The development of the energy system is presented in the following. Figure 2 shows the primary and secondary energy production for the 21st century, differentiated by the energy sources[2]. The primary energy production is increasing continuously in the next hundred year with a weakening annual increase. This is due to the population scenario, the decreasing growth of demand in the developed countries and the increasing rise in cost of fossil energy sources. The primary energy production will increase from almost 470 EJ to more than 1400 EJ per year.

The primary energy mix remains mostly based on fossil energy sources. Whereas the use of oil and gas remains constant, the use of coal is strongly increasing (particularly until 2030). Coal is here particularly used to produce electricity (see Figure 3) and replaces the conversion of gas and nuclear energy into electricity. Power generation will increase almost linearly by approximately 3.6 EJ per year to around 400 EJ at the end of the century, it is sixfold higher compared to the base year. The economic attractivity of coal is due to its lower costs, the flexible trade and the assumption that the use of coal is not subject to any regulations. However, there will be a price increase for coal around the middle of the century that makes the use of renewable energy sources competitive. Hydro energy and especially wind energy

[2]The primary energy production of the renewable energy sources wind, solar and hydro energy is put on the same level as the related secondary energy production.



(a) Primary energy



(b) Secondary energy

Figure 2: Global production of primary and secondary energy sources in the reference scenario

but also geothermal energy sources will increasingly be used for primary energy production. The use of biomass will also increase after 2030 which is due to its increasing availability. Nuclear energy will be used as a considerable supplement for coal at the end of the century.

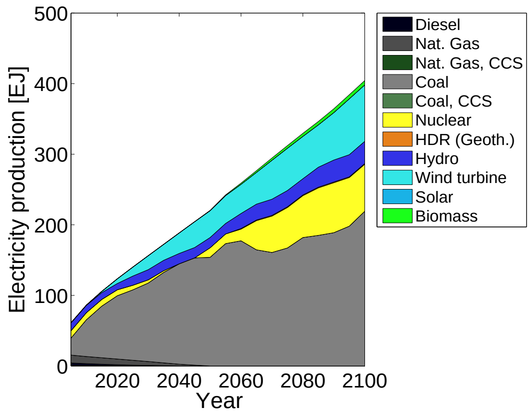
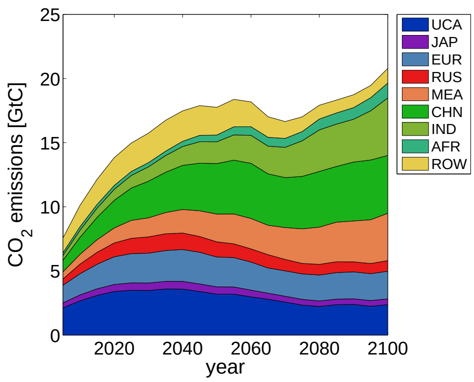


Figure 3: Global power generation in the reference scenario

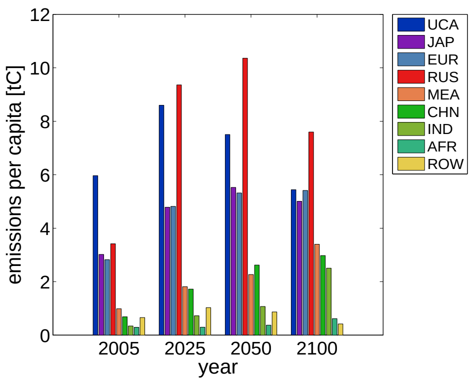
2.2 Emissions

From the analysis so far it inevitably results that there will be an increase of emissions. This is mostly due to the conversion of coal into electricity. The world-wide emissions amount to approximately 21 GtC (76 Gt CO_2) in 2100 (see Figure 4(a)). The increase of emissions is mainly quite high in the early decades - with a doubling of the emissions between 2005 and 2025. The temporary decrease of the emissions around 2060 is followed by another increase.

There still remain large differences in the per capita emissions (Figure 4(b)). While the industrial countries increase their per capita emissions until 2025 and keep them on a high level (5-9 tC per year), they rise to approx. 1.5-3 tC in China, India and MEA. The per capita emissions rise to more than 10 tC until the middle of the century in Russia and stay above 7 tC until the end of the century. Africa remains on a consistently low level with less than 1 tC per capita.



(a) World-wide emissions



(b) regional per capita emissions

Figure 4: Emissions in the reference scenario

While the emissions reach their maximum around 2040 in EUR and UCA, emissions are continuously increasing in India and China. The increase will be interrupted in China in the second half of the century. Coal is the main energy source in all regions which causes an increase of the emissions. But also the distinct reduction of the emissions around 2060 is linked to the use of coal (especially to the sharp decline in UCA).

3 Model analysis of post-2012 climate policy regimes

3.1 Description of the policy regimes

The following analyses are based on the 2°C target. Within each policy scenario, a global emission path has to be determined which meet the 2°C target. However, within REMIND-R the energy-related CO_2 emissions are under the control of the decision-maker only. Exogenous scenarios are applied for the development of the land use change CO_2 emissions and the non-CO_2 emissions. In the current model setting, drastic emission reductions have been provided by the energy sector. Global energy-related CO_2 emissions have to be reduced by 50% until 2035. The atmospheric CO_2 concentration reaches its maximum at around 415ppm in 2030.

In the analysis of how and at which costs such a reduction path can be achieved, we investigate three different designs of an international cap & trade system. In such a system, emission rights according to their reduction obligations will be allocated to the individual regions as of 2010. The endogenously determined global emission reduction path represents the world-wide available amount of emission rights.

Contraction and convergence (policy scenario A)

As of 2050, the same per capita emission rights are allocated in this scenario. By determining these allocations between 2010 and 2050, there is a smooth transition of the regional shares between grandfathering and same per capita emissions. 2000 is assumed to become the reference year for grandfathering.

Intensity target (policy scenario B)

In this policy scenario, the shares of the regions are determined by the globally available emission rights according to their shares in the world-wide gross product, i. e. each region receives the same emission rights per unit gross domestic product (GDP). In this policy scenario, the industrial countries are apparently provided with more emission rights than in the other two policy scenarios.

Multi-stage approach (policy scenarios C and D)

We selected a form of multi-stage approach in which the quantitative reduction obligations of the individual regions depend upon their per capita incomes. We distinguish four stages. Regions of the first stage are practically not obliged for any reductions. They can, however, participate in the emission trade and will be provided with certificates to the amount of their reference emissions. Regions of the second stage will be provided with emission rights to the amount of 0.15 GtC per 1 trillion $US gross national product (GDP). Since a growth of the GDP can be expected as a rule, this stage comprehends an increase of emission rights for the respective regions. Regions of the third stage are obliged to stabilise their emissions, while regions of the fourth stage have to significantly contribute to the emissions reduction. The share of global emission rights for these regions arises from deducting the number of certificates used for the regions of stage 1 to 3. The internal allocation between the regions of stage 4 follows again the above-described contraction and convergence approach.

As an additional variant of the multi-stage approach, we formulated a scenario in which only those regions participate in the emission trade which are either in stage 2, stage 3 or in stage 4.

3.2 Model results

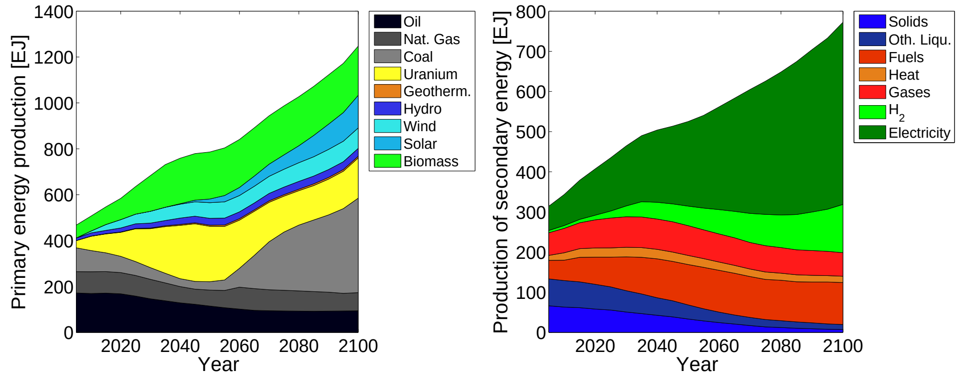
3.2.1 Policy scenario A: Contraction & Convergence

Mitigation costs We define mitigation costs as the difference of consumption between the policy scenario and the reference scenario. In policy scenario A, the average global mitigation costs are at 1.5%, at maximum approx. 2.5% with higher mitigation costs arising in the second half of the century. The regional costs are widespread around these global values. MEA needs to deal with the highest costs - nearly 10% in average. Russia and India are also above the world-wide average. At the same time, some regions like Africa and ROW benefit in policy scenario A. Africa benefits most with an average gain of almost 5.2%.

Technology development and power production Drastic changes in the energy system are induced by introducing climate policy. This can be seen in many different ways in all areas. The fundamental changes can be summarised in five options for action:

1. Reduction of the entire energy consumption.
2. Immediate expansion of renewable energy technologies for the production of high-value energy sources; expansion of nuclear energy.
3. Application of CO_2 capturing and sequestration (CCS) for the conversion of gas and coal into electricity.
4. Reducing the production of fuels and gases, since technical avoidance options do not exist here.

5. Reducing the production of the low-value energy sources solids and other liquids so that more oil and biomass is available for the production of higher-value energy sources.



(a) Primary energy

(b) Secondary energy

Figure 5: Global production of primary and secondary energy sources in the policy scenario A

The results are mainly discussed in comparison with the developments in the reference scenario. The entire energy production - primary as well as secondary - will be reduced (see Figure 5). The primary energy generation reaches now approx. 1250EJ at the end of the century, whereas 1430EJ were reached in the reference scenario. In the short run, primary energy generation is increasing less first and accelerates its growth then again; this was vice versa in the reference scenario. An output of only roughly 770EJ will be reached in secondary energy production in 2100, while roughly 910EJ are produced in the reference scenario. This drastic reduction is due to the composition of primary energy and the balancing according to the direct method of consumption. The most obvious change in the primary energy mix (compared to the reference scenario) is the strong restriction in the use of fossil energy sources and the stronger and premature expansion in the use of renewable energy sources and nuclear energy. As of 2060, solar energy will also play a role now. Solids and other liquids will already earlier be taken out of the system in secondary energy production. Gas, heat and fuels will be produced to a minor degree. The production of hydrogen and electricity, however, will even increase compared to the reference scenario. Electricity generation (see Figure 6) is going to reach 480EJ.

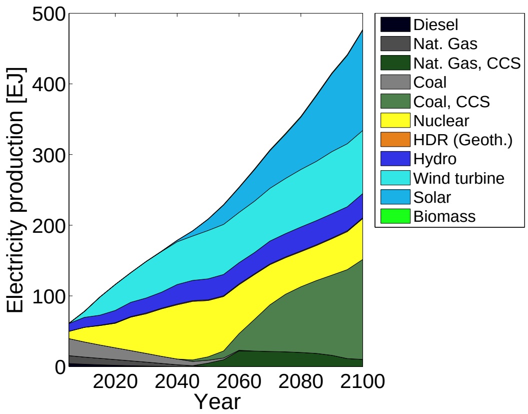
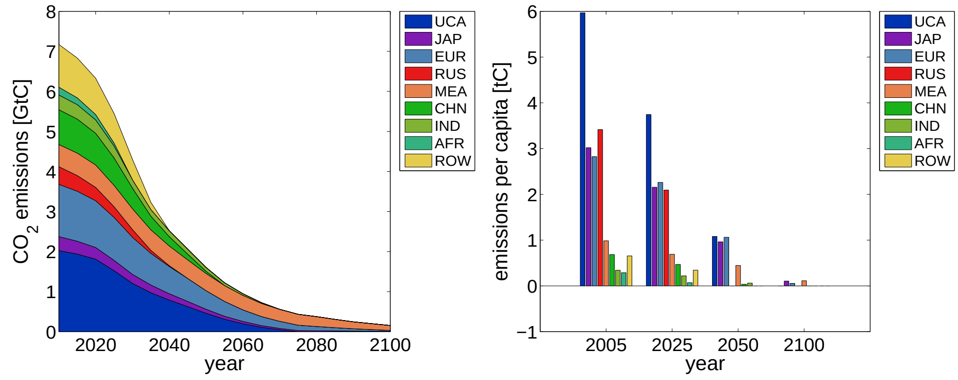


Figure 6: Global power generation in the policy scenario A

Expectedly, the use of wind, solar energy and water power is especially noticeable in the power generation mix. The premature expanse of these alternatives is especially remarkable. By the end of the 21st century the share of renewable energy production will be 56%. In the area of fossil energy sources, it can be observed that now gas is used for power generation; the emission restriction, however, demands CO_2 capturing. Coal will even on the long-term not be excluded from the generation mix. It is burnt in power plants according to the so-called oxyfuel method. This technology actually provides the most thorough capture technology, since only roughly one percent of the produced CO_2 will be released into the atmosphere.

It is to be summarised that the energy production, compared to the reference scenario, is much lower and that the structure will be modernised in a speedy manner. The low-value energy sources quickly lose their shares, while power generation will maintain its absolute share and hydrogen is gaining importance.

Emissions The pursued stabilisation scenario requires a fast and drastic decrease of emissions of all regions. Reductions are most drastic between 2025 and 2050 (see Figure 7(a)). The permit share of the developing world regions and ROW increases drastically. In the case of a missing emissions trading market, the industrial regions would need to decrease their per capita emissions to around 5% of today's



(a) World-wide emissions

(b) per capita emissions

Figure 7: Emissions in the policy scenario A

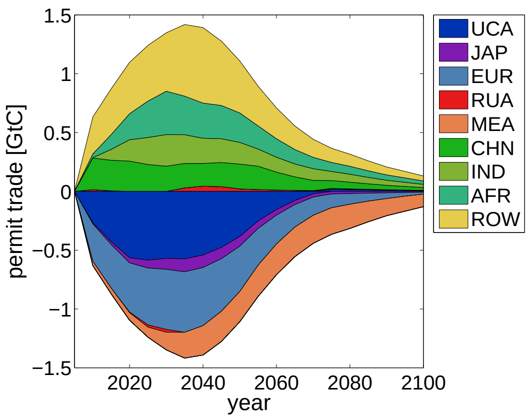


Figure 8: Emission trade in policy scenario A

level by 2050, in MEA, China and ROW to 20-25%, while India and Africa could still increase their per capita emissions. For both regions it is however obviously more favorable not to increase their own emissions and to sell the allocated emission rights profitably. Taking emission trade into consideration (see Figure 8), the reductions are lower in the industrial countries. Figure 7(b) shows that the respective per capita emissions would need to be reduced by approx. 20-35% in 2025 and by approx. 70-80% in 2050. Moreover, all regions need to reach per capita emissions of less than 1.2 tC per year in 2050, in 2100 even less than 0.2 tC.

3.2.2 Policy scenario B: Intensity target

Mitigation costs Policy scenario B produces in principle a different picture for mitigation costs than policy scenario A. Although the global average loss in consumption is the same, the regional distribution of costs is quite different. First, it can be noticed that Africa is not so clearly the only region to still benefit from the policy scenario. At least for the short term, negative mitigation costs can also be found in other regions (in particular in Japan and ROW). The consumption losses of UCA, EUR and China are slightly lower than the global average. Moreover, all industrialized regions have lower costs in policy scenario B than in policy scenario A. The regions MEA and Russia have further on higher costs than the world average, but also India bears high costs.

Technology development and power production The technological development in policy scenario B is the same like in the policy scenario A. This is due to the properties of an efficient market that generates the same allocation of scarce goods independent of the distribution of the emission permits among regions.

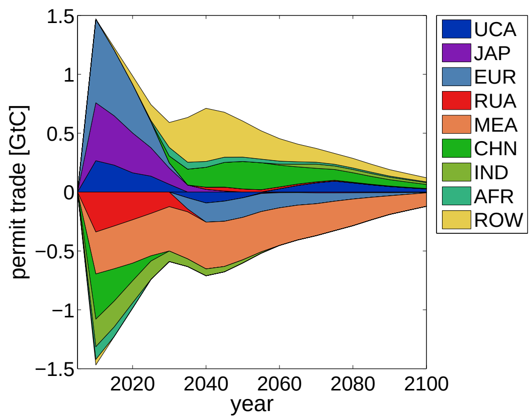


Figure 9: Emission trade in policy scenario B

Emissions The permit allocation is quite different between policy sceanrio A and policy scenario B. The latter allocates permits proportional to the regions' share on global GDP. Until 2050, the share of permits allocated to the developed world regions amounts to more than 50%. In this period, the bigger part of emission permits is allocated which additionally favours the developed regions. Despite the differences in the permit allocation and based on a different structur of emissions trade (see Figure 9), the emission trajectory and the regional structure of actual emissions is nearly the same (see Figure 7(a)).

3.2.3 Policy scenario C: Multi-stage approach

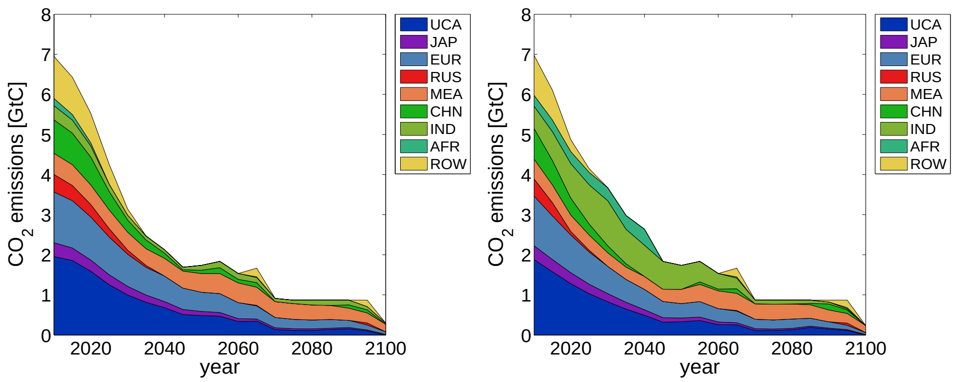
Macro-economic development and mitigation costs Again, MEA and Russia need to bear the highest mitigation costs. As distinct from policy scenario A and especially from policy scenario B, Africa benefits even stronger from a distribution of emission rights with a multi-stage approach. This is due to the fact that Africa is the region with the lowest per capita income and thus by the assumed allocation rule gets even more emission rights than in policy scenario A. As Africa can substitute easily away from the baseline use of fossil resources, an excess of permits results which can be sold profitably. This also applies to India which faces quite low consumption losses.

Technology development and power production Policy scenario C differs from scenarios A and B. In the short run less oil and gas is used in policy scenario C, that is substituted by an increase in the use of biomass and uranium. During the second half of the 21st century the development twists to the opposite: more oil, gas and coal is employed, but uranium use is reduced.

While gas shows a clear pattern of reallocation in time, for oil we observe also a different distribution between the regions: in the 2nd half of the century China reduces its gas consumption favouring all other regions. At the same time, China increases its consumption of coal. The use of uranium shows mainly a temporal redistribution, but the reduction of uranium use is most emphasised in India and Europe.

Emissions The permit allocation in the multi-stage scenario is featured by a fast increase of the developing regions' permit share. Already in 2030, UCA,EUR and JAP are allocated with less than 10% of global permits (while provided with 50% in 2010). Moreover, in contrast to policy scenario B, which despite different regional caps, come up with the same regional emission reduction paths like policy scenario A, policy scenario C (see Figure 10(a)) results in different paths. Globally, less emissions are produced in the short term, but more in the long term. The most demanding reduction phase, which is between 2025 and 2040, in policy scenario A and B is brought forward (between 2015 and 2030; in policy scenario D, characterised by emissions permit trade restrictions, even between 2010 and 2025 - see Figure 10(b)).

Whereas policy scenario A and B imply full flexibility in allocating global emission permits over time, policy scenario C and D imply predefined amounts of permits for the stages 1 to 3. This, on the one hand, results in a rather discontinuous profile of global emissions, and on the other hand, yield a higher amount of permits to be allocated in the second half of the century. In order to meet the climate target, the latter has, obviously, be compensated by a lower level of emission permits in the first half of the century.



(a) World-wide emissions

(b) World-wide emissions

Figure 10: World-wide emissions in the policy scenario C and D

3.3 Comparison of policy regimes

All policy scenarios pursue the same stabilisation target. Regarding ecological efficiency (i.e. its contribution to climate stabilisation), they are almost equal. Despite the same amount of global emission rights, the global emission course of the different policy scenarios is however not identical. This indicates inefficiencies in the distribution of emission rights. This effect, which applies to the multi-stage scenario, is however marginal here. Global average mitigation costs are between 1.4% and 1.5% for the policy scenarios A, B and C. Policy scenario D is most expensive with 1.6%.

Figure 11 provides an overview of the average regional mitigation costs for the four investigated scenarios. Policy scenario A and C have a similar cost structure for UCA, JAP, EUR, MEA and ROW. While the C&C scenario is more beneficial for Russia and China, Africa and India benefit significantly from the multi-stage scenario. Policy scenario B has the smallest range of regional mitigation costs. But at the same time, it is also a scenario of extremes. For most regions, it is either the most favourable or the worst scenario. It is most favourable for industrialized countries. The developing regions, on the other hand, need to bear significant mitigation costs. In the light of the distribution of the historical responsibility for the climate problem, this could be a heavy burden in future climate negotiations. Policy scenario D is acceptable for some regions, but certainly not for India. Altogether, the restriction made to the global emission trade system has a relatively high price.

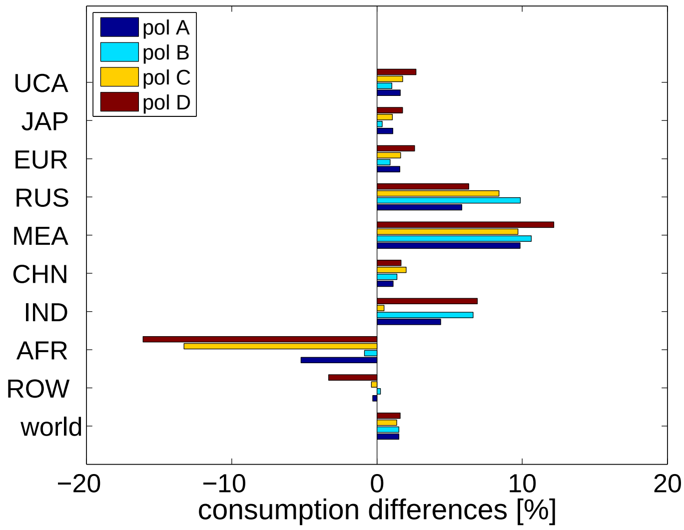


Figure 11: Average mitigation costs

As a robust result it turns out that the variance of mitigation costs is higher between the different regions than between the different policy scenarios. From the regional point of view, it should be noted that the region MEA has to bear the highest costs in all scenarios (always more than 9%). The reconstruction of the global energy system reduces part of the possible rents of this region whose revenues are to a large part derived from selling fossil resources. This is in a slightly milder form also true for Russia (always more than 5%). For the three developed regions UCA, Japan and EUR, the costs over the different scenarios develop according to a fixed pattern. The highest mitigation costs among this group can be found in UCA, they are slightly lower in Europe and they are lowest in Japan. Beside the different base level (highest per capita emissions in UCA), the growth pattern is also reflected in this relation according to which the region UCA will grow most rapidly among these three regions. For all three regions, policy scenario B is the most favourable one (mitigation costs amount to 1% or less). For China, the lowest costs arise in policy scenario A, however, variance of costs between the scenarios is contained. The contrary holds for India, where all scenarios but the multi-stage scenario are quite expensive. Africa benefits in all policy scenarios, most remarkably in the multi-stage scenarios (more than 10% consumption gains).

3.4 Analysis of mitigation options

Within the analyses of the previous section, it turns out that the use of different technological options is the optimal policy. Six options for action to avoid climate change were identified within the framework of the analysis of policy scenario A and B (contraction & convergence and intensity approach):

1. Lowering the entire energy consumption.
2. Modernizing the output structure of secondary energy carriers.
3. Reduction of fossil fuel derived transportation fuels and gases.
4. Use of renewable primary energy sources.
5. Use of nuclear energy.
6. Application of CCS for the use of gas, coal and biomass.

REMIND-R simulates relatively high shares of nuclear energy and use of coal based on CCS technologies. Risk aversion and a lack of social acceptance may restrict the use of both technologies. Based on the contraction & convergence scenario we defined two additional scenarios which restrict the use of the CCS technologies and of nuclear energy technologies.

3.4.1 No-CCS scenario

In this scenario, the application of CCS technologies either in combination with the use of coal and gas or in combination with the use of biomass is completely switched off. In consequence of switching off CCS, the energy consumption will be reduced significantly. This, above all, applies for the long-term. In 2100 primary energy consumption in the No-CCS scenario is almost 30% lower than in the C&C scenario which however is partly due to the different composition of the primary energy (a lower share of fossils means that in terms of secondary energy the energy consumption is reduced to a smaller degree). The remaining gap is filled mostly by solar energy and nuclear energy (see Figure 12). There is a reduction of global electricity production compared to the C&C scenario in the last 20 years of the century only. It amounts to less than 10%. While for the electricity production alternatives exist, the drop out of CCS technologies have a more drastic impact on the transport fuel sector and on the production of hydrogen.

The option value of the CCS technology is quite high. Mitigation costs increase to more than 2% globally (see Figure 14). UCA, EUR, Japan, Russia and MEA

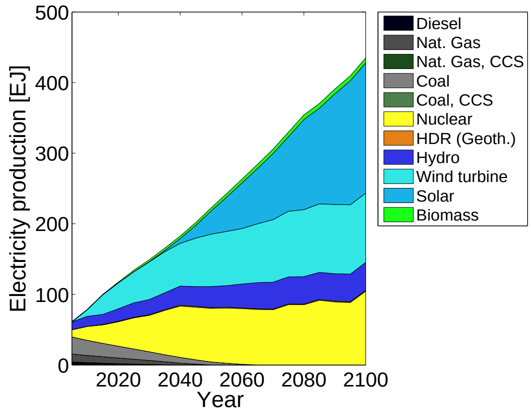


Figure 12: Global power generation in the No-CCS scenario

face highest additional mitigation costs, while AFR and ROW benefit. The drop out of CCS technologies increases the permit prices significantly. This improves the terms of trade of Africa and ROW.

3.4.2 Fixed nuclear scenario

In this scenario, the use of nuclear energy is fixed to the amount of the reference scenario. The reduction in energy consumption is less drastic than in the No-CCS scenario. The electricity production is quite similar (see Figure 13). Investments in CCS technologies (gas, coal, biomass) and solar technologies are brought forward, but can not completely compensate for the missing nuclear option. Other renewable energy technologies (Wind and Hydro) fill the gap in the short term. In the mid term (2030-2060) coal with CCS gains additional shares. Altogether, doing without additional nuclear energy is not at all very costly (see Figure 14). The option value of nuclear energy is quite low; the incremental mitigation costs are in the order of 0.2% globally. The nuclear option is slightly more important for Russia that faces highest additional costs compared to the C&C scenario.

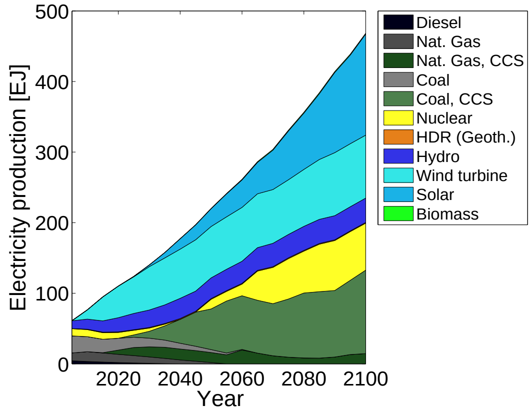


Figure 13: Global power generation in the fixed nuclear scenario

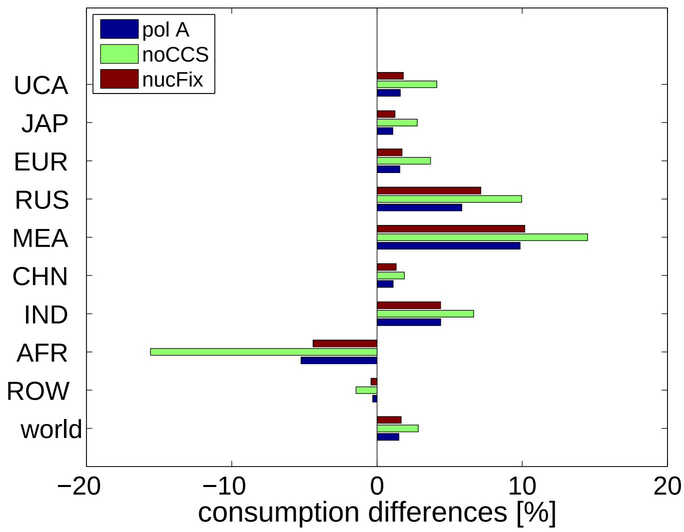


Figure 14: Average mitigation costs options

4 Conclusion

This study analyses the implications of suggestions for the design of post-2012 climate policy regimes on the basis. The focus of the analysis, the determination of regional mitigation costs and the technological development in the energy sector, also considers the feedbacks of investment and trade decisions of the regions that are linked by different global markets for emission permits, goods and resources. The analysed policy regimes are primarily differentiated by their allocation of emission rights. Moreover, they represent alternative designs of an international cap & trade system that is geared to meet the 2°C climate target. Based on the distribution of mitigation costs, the following conclusions can be drawn:

- Ambitious climate targets that meet the 2°C climate target with high likelihood can be reached with costs amounting to approx. 1.5% of the global gross product; this roughly confirms cost estimates of low stabilisation scenarios from earlier studies based on global models (IMCP study).
- The regional burden of emission reductions considerably varies with the particular designs of a post-2012 climate policy regime; however, the variance of mitigation costs between the regions is higher than between the policy regimes
- Regions with high shares in trade of fossil resources (MEA and Russia) bear highest cost
- (The majority of regional mitigation costs is in the range of -2% and 7%).
- Cap & trade systems based on a GDP-intensity target are more favourable for industrial countries (except for Russia), the contraction & convergence approach and/or the multi-stage approach are more favourable for developing countries.
- The global average mitigation costs are nearly the same for different allocations of emission permits.
- Africa can considerably benefit from an integration into a global emissions trading system.
- Doing without the nuclear energy option is not costly, but forgoing the CCS option will increase the global mitigation costs by more than percentage point.

The present study analyses ambitious climate protection scenarios that require drastic reduction policies (reductions of 60%-80% globally until 2050). Immediate and multilateral action is needed in such scenarios. Given the rather small variance of mitigation costs in major regions like UCA, Europe, MEA and China, a policy regime should be chosen that provides high incentives to join an international agreement for the remaining regions. From this perspective either the C&C scenario (Russia) is preferable or the multi-stage approach (Africa and India).