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International climate regimes: Effects of delayed participation

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Abstract

This paper analyses how delayed participation by regions can affect international climate regimes in terms of the feasibility, costs, timing, magnitude and nature of the long-term mitigation response. We use the energy-systems optimization model MESSAGE to construct several climate change mitigation scenarios with various levels of regional participation in short-to-mid term. By comparing these with a global scenario that assumes full spatial and temporal flexibility throughout the century, we are able to evaluate how participatory decisions affect the mitigation response as well as the costs and technology choices. We find that short-term postponement of participation from some regions can often lead to a delay of mitigation measures on the global level. However, if the regional delay lasts until mid-century, participants of the regime are likely to increase their efforts in the short term. Mitigation costs are found to substantially increase as a result of delayed participation—the extent of the increase depends on the relative importance of the region that postpones its participation, the stringency of the climate target and the ability to reorganize mitigation measures. Our analysis also shows that a region's decision to delay its participation in an international climate regime can lead to accumulated inertia in its energy system and thus to a delayed 'technological transition' toward a low-carbon future.

Keywords: Climate change; Energy modeling; Abatement cost; Delayed participation

1. Introduction

The UNFCCC [1] lead to the development of an international climate regime and established differentiated commitments for industrialized and developing countries. This was followed by the Kyoto protocol that mandated reductions for industrialized countries. However, the withdrawal of the USA from

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the Kyoto agreement and the continued non-binding stance adopted by developing countries has lead to speculation on how such participatory actions of the involved parties affects the costs and feasibility of international climate regimes. While an international cooperative and voluntary agreement to curb global greenhouse gas (GHG) emissions is still the most cost-effective way to combat climate change, in practice, it is complicated because of free-riding incentives and strong economic and environmental asymmetries between the actors.

The central issues to accepting binding commitments under any climate agreement involve equity and economic growth. Developing countries have, so far, rejected any binding commitments on the basis of historically low contributions to the current emissions burden as well as that to comply with such stringent regimes implies constraints on economic growth. This is especially an issue in countries like China, which is experiencing high economic growth and is projected to do so for the next few years. In addition, some of these regions are heavily endowed with fossil resources and the shift to low-emissions alternatives implies large investments into energy infrastructures, which compete with other pressing financial needs in these countries. The non-participation of industrialized countries (e.g., the US withdrawal from the Kyoto agreement) is also related to equity debates and the non-obligatory stance adopted by the developing countries.

An ideal fully global climate regime is today confronted by the reality of an ‘incomplete’ one in which certain countries adopt a wait-and-watch policy, while others accept and comply with emissions reduction commitments. There have been many studies related to climate agreements, including penalties and legalities in climate agreements [2,3], reconsidering the stringency of the long-term climate target [4], and game theoretical approaches on cooperation for climate control [5,6]. However, in general, most long-term climate-policy studies ignore the important aspects of potential uncooperative behavior[1] and free riding [7]. They mainly assume full global flexibility in the mitigation response (a discussion on the possible implications of this assumption is published [10]) or study postponed regional action from the perspective of predefined burden-sharing rules and global emissions paths [11–14]. Therefore, such climate policy studies mainly either present results for a fully when-and-where flexibility case in which the timing and distribution of mitigation efforts are based on a global cost-effective solution or, alternatively, determine the mitigation and emissions paths based on predefined burden-sharing rules without real when-and-where flexibility (i.e., the global emissions path for reaching a given climate target is not an optimized result, but a predefined input).

The main problem with studies that present the optimal results of a policy is that such a policy is only optimal if, in fact, all parties enact it. As with other uncertainties, such recommendations may not be robust if we take into account the fundamental political uncertainty that underlies international climate agreements [4]. Emissions trajectories and mitigation analysis based on predefined burden-sharing rules, while being relevant to address short-term policy decisions, are often inflexible with regard to the timing of emissions reductions. In this context, it has become necessary to try and devise climate mitigation frameworks that, while accounting for the possible non-participation of regions in a climate regime, still offer the flexibility for regions that participate in such regimes to cost-effectively distribute the emissions reductions over time. This approach has the advantage of still leading to a cost-optimal emissions pathway, even when non-participatory actions are taken into account.

In a first step in such a direction, here we analyze the case in which certain regions choose to delay their involvement in specific mitigation efforts until a given time period and the effect this has on the feasibility, costs, timing, magnitude and nature of the mitigation response. Delayed or non-participation of certain

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[1] However, the effect of the US withdrawal from the Kyoto treaty has been studied widely, especially for the short-term consequences [8,9].

large emitters in a global climate regime not only has serious implications for the overall effectiveness and feasibility of the policy, but also potentially affects the behavior of the participating regions. The rapidly increasing emissions in most developing countries imply a much larger share in the global burden in the future (as compared with industrialized countries) and hence their refusal to accept any binding agreements may lead to non-participation of developed countries as well. It is unclear whether the participating regions would try to compensate for the increased emissions from the non-participating region or, alternatively, postpone further reductions until later when all the regions contribute to the effort. In addition, given global trade flows and technology transfers, delayed participation of a region also has implications for the region itself, in terms of its individual costs, technology choices and trade patterns.

We do not examine either the reasons for non-participation or the possibilities for ensuring compliance and participation.[2] It is important to emphasize from the outset that this not an innovative tool to deal with issues of participation and compliance, that is, we do not investigate the political motivation for such actions and nor do we propose mechanisms to ensure participation. We mainly present a sensitivity framework for a wide range of scenarios with limitations on the spatial and temporal mitigation flexibility and in which the uncertainties that concern regional participation are considered in a stylized manner. We then compare and contrast the resulting emissions, costs and technology choices with those from scenarios in which fully flexible global participation is assumed. In that sense we go beyond the majority of the global scenario literature, which has traditionally assessed the implications of climate stabilization from a full 'when-and-where' perspective or with predefined mitigation paths and burden-sharing rules. Instead, we estimate the technological and financial consequences of a temporarily limited 'where' flexibility for a large number of regions. The wide range of emissions scenarios that we consider with different assumptions concerning the baseline-dependent socio-economic assumptions, stringency of the set climate targets, regional level of cooperation in the climate regime and the duration of the postponement of participation provides us with a comprehensive basis for a sensitivity analysis. We can thus make robust conclusions concerning the effects of the delayed action of chosen regions in a global mitigation scheme.

2. Case study setup and main assumptions

This study uses the MESSAGE model [18], a perfect foresight systems-engineering optimization model used to describe an energy system with all its components, ranging from resource extraction to the end-use level. The model has been constantly expanded and recently non-CO_2 GHGs were included within it [19]. The model has a rich, bottom-up technology database that is used to describe the energy system from the resource extraction to the consumer. Mitigation options related to land use are also included in the modeling framework (also discussed in this Special Issue [20]). Fig. 1 indicates the world divided in 11 regions according to the MESSAGE model. In addition to this, a further aggregation into four regions is shown. We use the regional abbreviations shown in Fig. 1 throughout this paper.

The baseline scenario is an important part of any scenario-based analysis as different baselines have different implications for mitigation needs, dynamics of technological change and fossil fuel availability

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[2] In our modeling framework, non-participation or postponement of participation is essentially the same as non-compliance as we do not assume any additional penalties for compliance. Several suggested climate policy architectures and their effectiveness in terms and compliance are given elsewhere [15,16]. Bodansky [17] also offers a fairly comprehensive survey on different approaches for post-Kyoto international climate efforts.

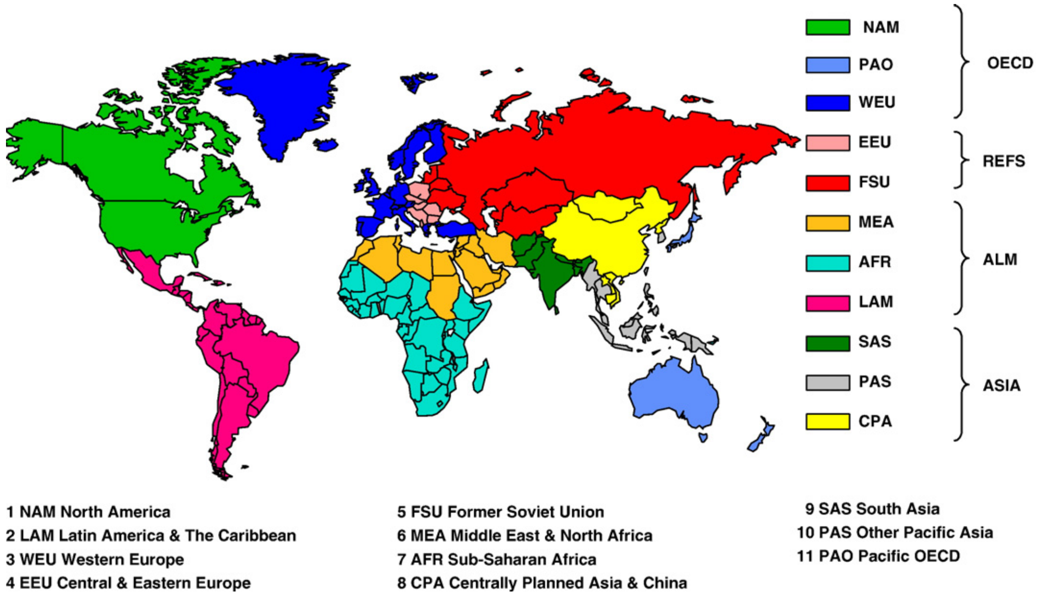

Fig. 1. The 11 world regions in MESSAGE.

(a description of the scenario families is given in a previous issue [21]). We analyze two baseline scenarios, A2r and B1, described in detail in this Special Issue [20].[3] Table 1 shows the basic indicators of these two baseline scenarios.

In addition to differences in the baselines, the severity of the climate target can be expected largely to influence the mitigation response and the non-participatory regimes. To examine such effects, we develop an analysis with multiple mitigation scenarios based on the following combinations of baselines and CO_2 equivalent concentrations,[4] and which correspond to the following temperature changes at the end of the century (measured at a climate sensitivity of 2.5 °C):

- A2r-660 (660 ppm, 2.3 °C)
- A2r-850 (850 ppm, 2.9 °C)
- B1-510 (510 ppmv, 1.6 °C)

These scenarios have full when-and-where flexibility, as the constraints are formulated in terms of global cumulative CO_2-equivalent emissions between 2000 and 2100. This means that there are no predefined regional or global emissions pathways and the only criterion is that the cumulative limit is not exceeded during the century. In addition, these scenarios represent optimum or cost-efficient mitigation

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[3] The scenarios analyzed in this paper are broadly based on the same socio-economic, demographic and technology assumptions as summarized in this Special Issue [20], but, because of the large number of sensitivity runs required, we concentrate mainly on the MESSAGE modeling framework and omit the macroeconomic feedback component. Thus our numerical results differ slightly from the corresponding scenarios of the Riahi et al. analysis [20]. Although land use, non-CO_2 GHG emissions and local pollutants are a part of our scenarios, as detailed in this Special Issue [20,22], we do not comment on them here.

[4] Inputs and implications for climate-related variables are given in this Special Issue [20].

Table 1
Population, gross domestic product and greenhouse gas emissions in A2r and B1

	Year	A2r	B1
Population (million)	2000	6054	6054
	2030	8711	8181
	2060	10,863	8665
	2100	12,384	7055
GDP (trillion $)	2000	27	27
	2030	60	73
	2060	119	172
	2100	189	328
Greenhouse gas emissions (Mton C_{eq}/year)	2000	10,096	10,096
	2030	18,535	12,928
	2060	28,007	11,907
	2100	37,907	7858

structures that assume full global participation of all regions. This efficient mitigation strategy implies that an emissions trading scheme is present and emissions reductions are always made where and when they are cost optimal. The current setup can therefore be interpreted as a mitigation regime with international emissions trading without transaction costs. However, since we do not use any burden-sharing rules to define which regions are buying permits and which ones are selling, we do not model the monetary flows that results from this trading scheme. We also do not account for changes in economic welfare that may occur through the increased revenue from such trading. In addition, demands are inelastic to price changes, which could imply higher mitigation costs compared with price-responsive structures and also, to some extent, limits to the possibility of even more stringent mitigation scenarios. However, lower energy-system costs because of lowered demand may also imply additional investments on the demand side, which may reduce this difference to some extent.

For compactness and simplicity, we chose to concentrate mainly on the A2r baseline scenario and the A2r-660 mitigation scenario in this analysis and only present results from the other scenarios wherever relevant.

To conduct a sensitivity analysis on how such efficient global regimes are affected by the delayed participation of certain regions, we construct a number of mitigation scenarios based on certain regions choosing to stay out of the regime until a given year. For the cut-off points, after which the non-complying region joins the mitigation scheme, we use the years 2030 and 2060.[5] It is important to keep in mind that in our setup no region stays out of the mitigation regime forever; it simply delays its joining for a certain period. Table 2 shows the combination of scenarios that we ran, as well as the identifiers used for the scenarios.

We name our scenarios by using the abbreviation of the non-participating region and adding the identifier shown in Table 2, derived from the final year of non-participation (3 for 2030 and 6 for 2060). For example, NAM3 (North America delays its participation until 2030 with A2r as the baseline under a climate target of 660 ppm CO_2-eq), CPA6a (centrally planned Asia and China delay their participation until 2060 with A2r as the baseline under a climate target of 850 ppm CO_2-eq) or ASIA3b

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[5] The selection of the period of delayed action or non-participation is arbitrary and is not based on any specific analysis.

Table 2
Identifiers for the 32 feasible scenarios run

Non-complying region	Scenario		
	A2		B1
	Mitigation target (ppm CO_2-eq) in 2100		
	660	850	510
CPA	3/6	3a/6a	3b/6b
NAM	3/6	3a/6a	n.a.
LAM	3/6	3a/6a	n.a.
SAS	3/6	3a/6a	n.a.
ASIA	3/6	3a/6a	3b/6b
OECD	3/6	3a/6a	n.a
GLOBE	3/inf	3a/6a	3b/inf

'Inf' means the scenario was infeasible (i.e., the mitigation target was not reached), and 'n.a.' that the particular combination was not explored. For the definitions of regions, see Fig. 1.

(ASIA delays its participation until 2030, with B1 as the baseline under a climate target of 510 ppm CO_2-eq). For the key indicators of all the non-participation and full-efficiency mitigation scenarios, see Appendix A.

In our methodology, the temporary non-participation of a region always represents movement away from the least-cost mitigation scenario. 'Emissions trading', as defined before, is still available for the regions that participate in the mitigation regime, but no mitigation efforts occur in the regions that do not participate (i.e., we do not include any technology transfer or CDM-type instruments in our setup). As a result, the regions that delay their participation follow their baseline emissions pathways until the time period they join the regime. This delay, in effect, means that the full where-and-when flexibility of emissions reductions no longer holds, as the possibility of emissions reductions is not available to non-participating regions for a particular period of time. However, there will be no increased emissions (above the baseline) in these non-participating regions either, since the perfect foresight of the model together with the nature of the cumulative emissions constraint also encourages these regions to keep their emissions no higher than in the baseline. After a region joins the mitigation regime, it fully participates in the emissions trading (i.e., there are no penalties for its delay). Under imperfect foresight, a region might have higher emissions than in the baseline as it does not foresee its eventual participation and may increase its consumption of emission-intensive fossil fuel because the lower demand for these fuels in the participating regions leads to a corresponding decrease in global fuel prices.

Under this temporarily incomplete climate regime, the participating regions may decide to further increase their mitigation efforts and thus 'make up' the mitigation gap caused by the non-participation of a region. Alternatively, because the emissions constraints are cumulative and global, they can decide to postpone the additional mitigation needed until later, when all regions are again participating in the regime. This decision as to whether to redistribute the lost mitigation temporally, spatially or both depends strongly on how difficult it is to reach the given climate target, defined in terms of cumulative global emissions over the century. Importantly, the long-term target that has been set has to be met and is not reconsidered even if some regions do not enter the regime from the beginning.

As shown in Table 2, we explored in total 32 different feasible non-participation scenarios, and to present the full analysis for all of them individually is not an option here. For purposes of clarity, we use scenarios NAM3 and CPA3 as our main examples, but offer additional insights from the other scenarios whenever appropriate. We choose these two scenarios mainly because they allow us to estimate the short-term effects on a mitigation regime that result from the postponed action of an important region. These two regions can be considered as important from the perspective of any climate regime, since the USA (included in the region NAM) is the largest economy in the world and responsible for a sizable share of the global GHG emissions. CPA, on the other hand, includes China, which is among the fastest growing economies in the world and its GHG emissions are expected to double from 2002 to 2015 [23]. Furthermore, China is also considered to have a large potential for emissions reductions. Neither of the two main countries in the chosen regions is a participant in any current international climate agreements that contain emissions reductions with binding limits.

The main three research questions we try to address are:

(1) What effect does the regional postponement of participation have globally on the temporal and spatial distribution of mitigation efforts?
(2) Will regional non-participation have an effect on the development of energy structures, either in terms of direction or timing?
(3) What is the cost effect of regional non-participation on the global scale?

3. Results

In this section, we present results on the effects of the different mitigation regimes when compared with the ‘full efficiency’ mitigation scenario. We look into how participation actions affect the costs, timing, magnitude, feasibility and nature of the global mitigation response. Special attention is paid to the short-term implications of delayed participation, given a long-term climate target.

3.1. Emissions and mitigation

Fig. 2 presents the emissions paths for A2r, A2r-660 and A2r-850, as well as for the range of regional non-participation scenarios. We observe that the short-term delay in participation does not produce a very pronounced long-term difference compared with the regime with global participation (A2r-660). However, long-term non-participation tends to produce only relatively small divergence from the full-efficiency case in the short term. This indicates that the effect of a partly delayed participation in the latter scenarios is dominated by the certainty of a stringent climate target and complying regions, therefore, often tend to increase their efforts. To some extent, this result is a natural outcome of our modeling methodology and the assumptions of perfect foresight. In the real world, we would expect a climate stabilization target over a period of 100 years to either be a dynamic one or be translated into specific regional emissions commitments (as in the Kyoto protocol) that could be renegotiated.[6]

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[6] We ignore here the uncertainty of the climate effect and the possibility of reconsidering the target itself if; at some point, it becomes clear that the magnitude of the impacts are different to those originally estimated or if assimilated adaptive capacity proves to become dominant.

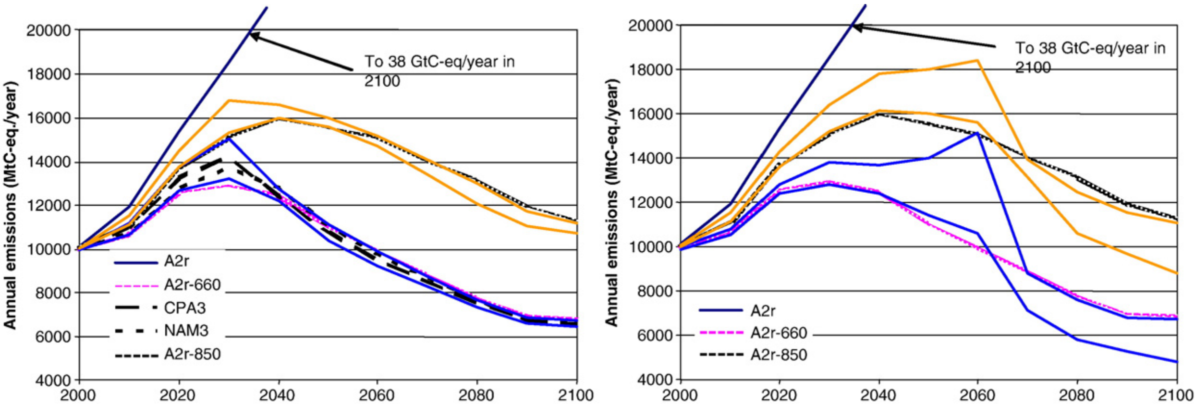

Fig. 2. Emissions paths for the non-participation cases that last until 2030 (left panel) and until 2060 (right panel) for scenarios A2r-660 and A2r-850. Solid light gray (orange) and dark gray (blue lines) show the range of all regional non-participation scenarios for these targets. (For a color version of this figure, see the electronic edition.)[7]

Another observation is the effect of temporary non-participation on the feasibility of the climate target imposed.[8] If the delayed action from a particular region leads to an unfeasible mitigation target, this implies that the defined climate target requires the participation of this region. Our results, however, indicate that no single region (or aggregated region) has such an effect, at least not with the selected targets and timelines for postponed participation. The only scenarios that prove to be unfeasible are the GLOBE6 and GLOBE6b (i.e., the scenarios in which action is delayed globally until 2060). Since an infeasible scenario occurs only when the formulated optimization problem is infeasible, this result indicates that, if mitigation is postponed this far in these scenarios, no amount of additional cost can make it possible to achieve the targets. However, this result also indicates that postponement of action or delayed compliance is a question of costs alone in all the other feasible cases and the given target is, at least *technically*, attainable. Scenario assumptions concerning uncertain parameters, like technological progress, population growth or economic trends, can, of course, affect these results and different assumptions might lead to different conclusions.

Fig. 3 shows the contribution of each region to the total mitigation effort to the years 2030 and 2100 in the full efficiency A2r-660 scenario. It seems clear that under an optimal mitigation scheme the developing countries remain prominent contributors to mitigation efforts from the start of the global regime. We also see that the regions NAM and CPA together are responsible for 45% of the emissions reductions achieved to 2030 and still almost 40% by the end of the century. The combined ASIA region (SAS+PAS+CPA) already contributes close to 40% to the mitigation efforts in the short term. Postponement of participation by these regions in the mitigation regime is likely to cause considerable changes in the global energy system, in both the short and long term.

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[7] Global warming potentials have been used to translate non-CO_2 GHG emissions into CO_2 equivalent emissions. More on the methodology and values used is given elsewhere [19].

[8] Our definition of feasibility is closely related to the amount of inertia gathered in the energy system through non-compliance and whether this inertia is too large to meet a climate target. This means that we define it in terms of whether the optimization problem has a feasible solution or not, and we do not make any estimates on whether the costs, burden sharing or technological changes of the system would be possible to implement in real life, politically or otherwise.

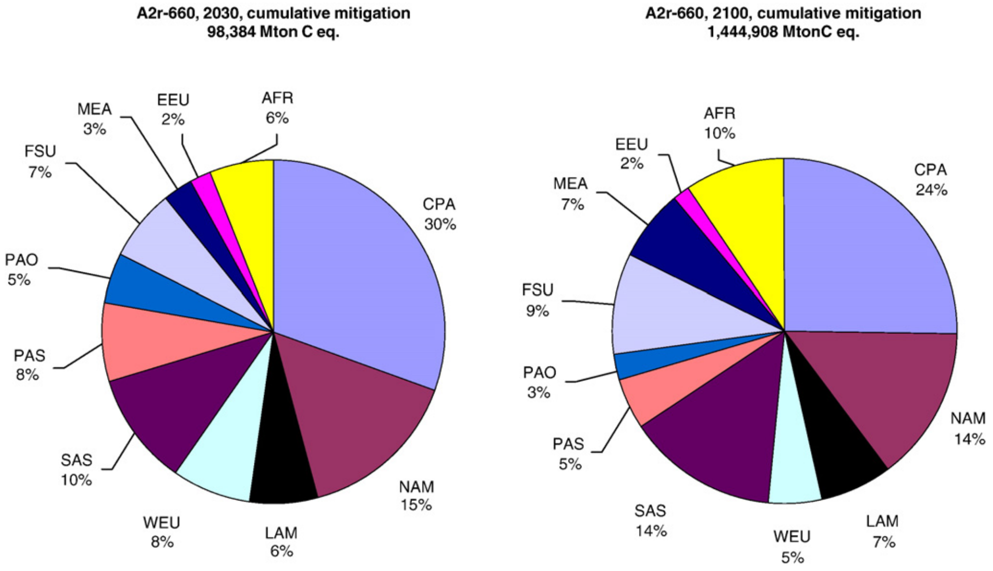

Fig. 3. Regional cumulative emissions reductions for the full-efficiency mitigation case, A2r-660.

An important point is that in this analysis we do not explicitly establish how the *costs* of mitigation are distributed among regions. The full 'where-and-when' flexibility of our model means that reductions are always done where it is optimal to do them. This optimal distribution of mitigation corresponds to a mitigation regime with emissions trading without transaction costs. However, we make no assumptions on the burden sharing (i.e., regional caps) and therefore do not make any arguments on how mitigation costs are distributed among regions.

Delayed participation of one of the regions is likely to change the mitigation strategy of the other (participating) regions. However, the timing of participation is an important determinant of how the remaining regions respond to this. The short-term mitigation efforts and their distribution of the burden between regions for the various scenarios are presented on the left panel in Fig. 4. For cases in which non-participation lasts up to 2030, we find that the global cumulative mitigation remains below the levels of the full-participation scenario A2r-660. In other words, the participating regions do not compensate in the short term to the extent of mitigation achieved globally in A2r-660, since they are aware that the non-participating region will become part of the mitigation effort at a later stage. However, this means that, since fewer reductions are made globally during the first three decades, increased global efforts are needed later during the century. Thus, we conclude that the short-term delayed participation by a region in a global mitigation scheme does not automatically imply a simultaneous increase in mitigation efforts by the participating regions, but does lead to an increase in the required mitigation efforts later on. This emphasizes the importance of a wide participation of nations in any global mitigation scheme to build the depth and breadth necessary in the long term to address the climate problem in meaningful ways [24].

Non-participation of a region for a longer period of time, however, can lead to very different outcomes. As the right panel of Fig. 4 shows, if the complying regions do not expect participation of the non-complying region during the first half of the century, then emissions reductions in the short term are much higher than for a briefer period of non-participation—in several cases, the global reductions are even

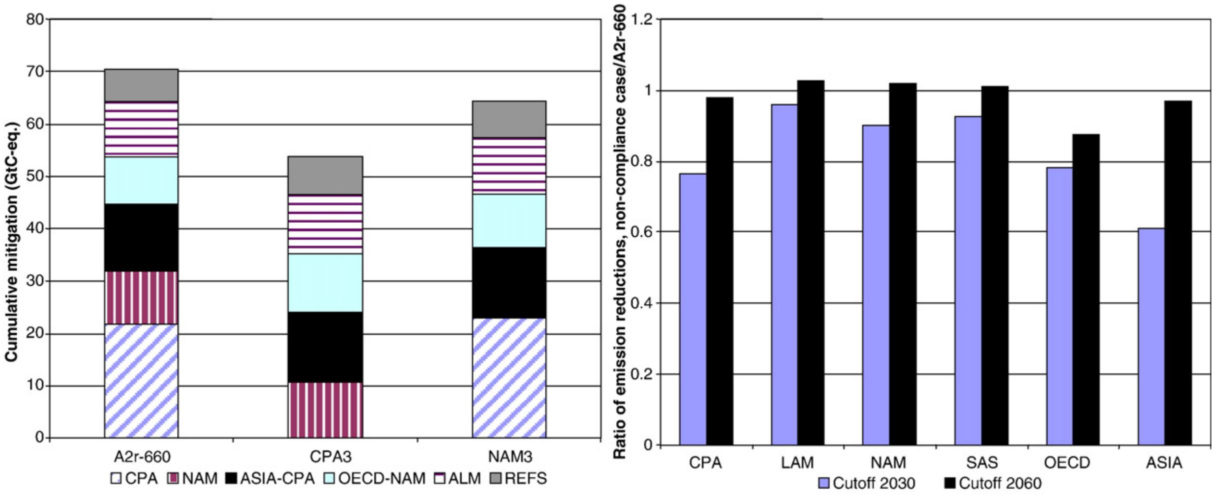

Fig. 4. The extent and regional distribution of short-term (until 2030) emissions reductions (left panel) and ratio of global emissions reductions achieved in the non-participation cases and A2r-660 by 2030 (right panel).

above the levels of A2r-660. In these cases, the emissions target can no longer be reached if no additional efforts are made in the short term by the participating regions and, because of this, mitigation levels close to or above of those experienced in A2r-660 are observed. To some extent, the delayed participation until 2060 by one region changes the decision of postponement of mitigation on the global level from one of cost minimization to one of feasibility. In other words, the results indicate that, if some regions delay their efforts into the second half of the century, this might mean that, unless other regions try to increase their efforts to cover up this ‘mitigation loss’, the final target might remain out of reach. Since, in the real world, there is no ‘perfect foresight’ concerning the start of a truly global mitigation regime, decisions of to postpone, following the logic shown by our results, include a genuine risk of not being able to reach the target.

The power sector is responsible for a large share of the GHG emissions in all scenarios. Therefore, the mitigation efforts are also likely to show themselves most clearly in this sector. Examining the electricity production in the full-efficiency scenario A2r-660, we find that mitigation changes the structures of the electricity production sector by increasing the use of emissions-free on-site technologies, large-scale centralized emissions-free technologies (especially nuclear) and add-on technologies used to reduce emissions from power plants fired with fossil fuel. In general, traditional emission-intensive solid- and liquid-based fuels are substituted by cleaner grid-based ones (e.g., electricity) produced with emissions-free technologies. These energy carriers are also used more in the transportation sector and for heating purposes (especially with heat pumps). Fig. 5 presents the changes (compared with the full efficiency mitigation case) in electricity production for two non-participation cases. Gas is not included, since very little gas is used for electricity production after the year 2050 in A2r-660.

Although the non-participation mitigation cases have a similar tendency to move toward cleaner technologies as that in the full-efficiency scenario, some clear differences can also be observed, especially through the duration of the regional postponement of action. In the short term, coal-based electricity production is clearly increased in both of the non-participation cases shown in Fig. 5. This increase in coal-based electricity production continues for several decades beyond the point after which the initially

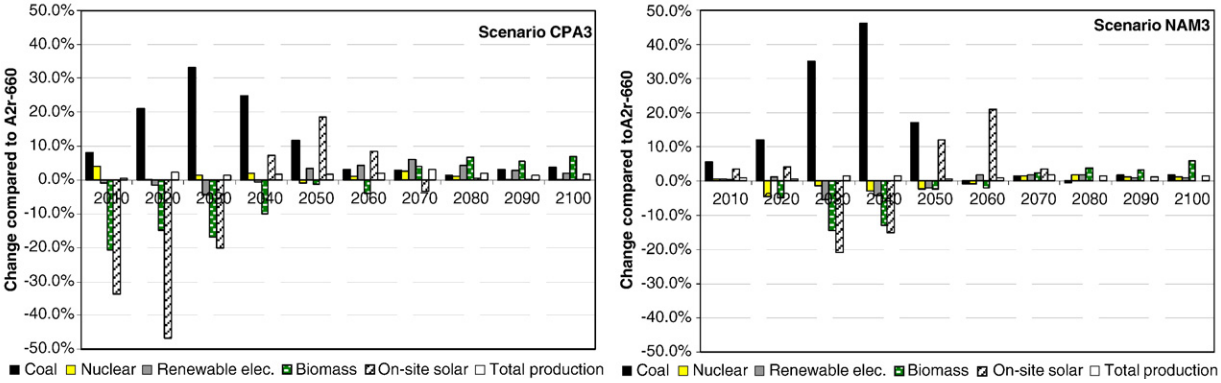

Fig. 5. Changes in annual global electricity production by fuel for scenarios CPA3 and NAM3, A2r-660 as reference level.

non-participating region joins the mitigation scheme. This results from the inertia in the energy system-power plants that were built between the years 2000 and 2030 are retired between 2030 and 2060. This effect is, naturally, especially strong with the fossil-heavy baseline A2r, on which scenarios CPA3 and NAM3 are based.

Fig. 6 further demonstrates the above effect regionally by showing the installed coal power-plant capacity in the region CPA in 2030 for scenario CPA3 and in the region NAM in 2030 for scenario NAM3. As the figure shows, existing capacity is approximately twice as high as it is in scenario A2r-660. The total cumulative investments in coal power plants for scenario CPA3 in the region CPA increase from approximately 330 to 700 billion dollars by the year 2030. This translates to an average annual increase of more than 12 billion dollars extra investments made in coal power plants. By 2030, almost 50% of the cumulative investments in electricity generation are made in coal power plants.

Additionally, in the case of CPA3, this increase in capacity and use of coal for electricity production is achieved with conventional coal power plants with a single steam cycle. Hence, the more advanced coal power plants, mainly integrated gasification combined cycle (IGCC), penetrate the markets in this region decades after they do in the A2r-660 case, in which they dominate other coal power plants from quite early

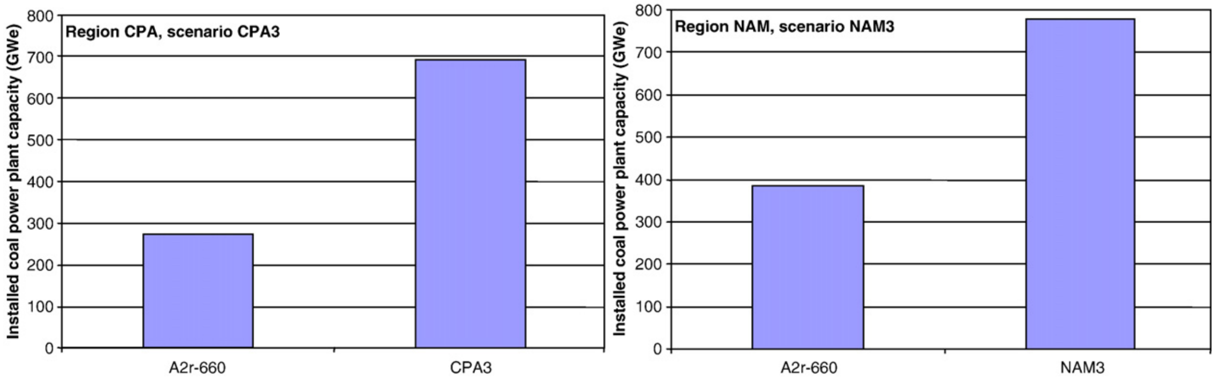

Fig. 6. Installed coal power capacity in the year 2030 in the region CPA for scenario CPA3 (left panel) and in the region NAM for scenario NAM3 (right panel).

on. Furthermore, carbon capture technologies are also slower to penetrate, since the conventional coal power plants require post-combustion capture technologies, which are not nearly as competitive as the pre-combustion technologies that can be used with the more advanced IGCC plants. Finally, this large increase in coal use also implies a much slower overall structural change in the regional energy system toward low-carbon technologies. In the region CPA, the shares of carbon-free energy and of total emissions are comparable to the levels in A2r-660 only by 2050. Again, although similar effects are observed with scenarios based on baseline B1, the high fossil-fuel intensity of baseline A2r causes the effects presented here to be stronger.

On the global level, renewable electricity production and carbon-free primary energy use in scenarios CPA3 and NAM3 remain above the levels of the A2r-660 scenario throughout the latter half of century. This implies that more emissions reductions are made in the latter half of the century in scenarios NAM3 and CPA3 than in A2r-660. This, in turn, indicates that other regions do not completely make up for the mitigation lost because of the non-compliance of single region during the time of non-participation, but at least partly postpone the mitigation to latter periods. Finally, it seems that non-participation further increases the production of electricity and there is a small but consistent increase in total electricity produced. This may very well again be because even further emissions reductions are needed as a result of the lack of action taken in one region before 2030.

3.2. Cost of postponement of participation

The non-participation of certain regions in the climate regime has significant implications not only for the overall costs of achieving the long-term climate target, but also for the temporal and spatial distribution of these costs. The timing and the extent of these additional costs depend on the relative importance of the region that postpones its participation in the mitigation regime.

The left panel of Fig. 7 shows how the non-participation of different regions for different durations affects the overall mitigation cost. For the CPA3 scenario, mitigation costs increase for the duration of non-participation and reach a peak in 2030, the period the CPA region joins the climate regime. The increase in costs and that emissions reductions in this scenario until 2030 are below the levels of A2r-660 (see Fig. 4) indicate that the average cost per ton of CO_2 removed is relatively high for this duration, as is

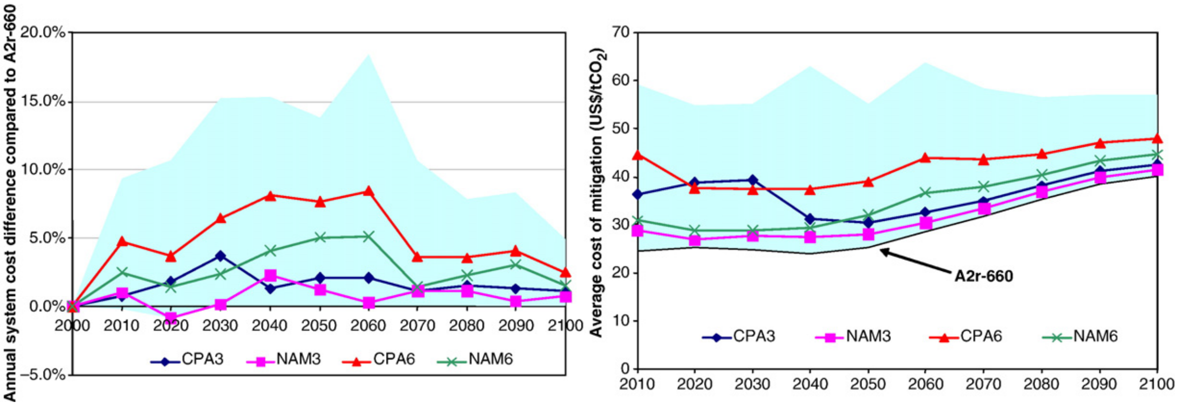

Fig. 7. Changes in global annual system costs compared with the A2r-660 (left panel) and the average cost of cumulative mitigation by period (right panel). The shaded areas show the range across all A2r-660 non-participation scenarios.

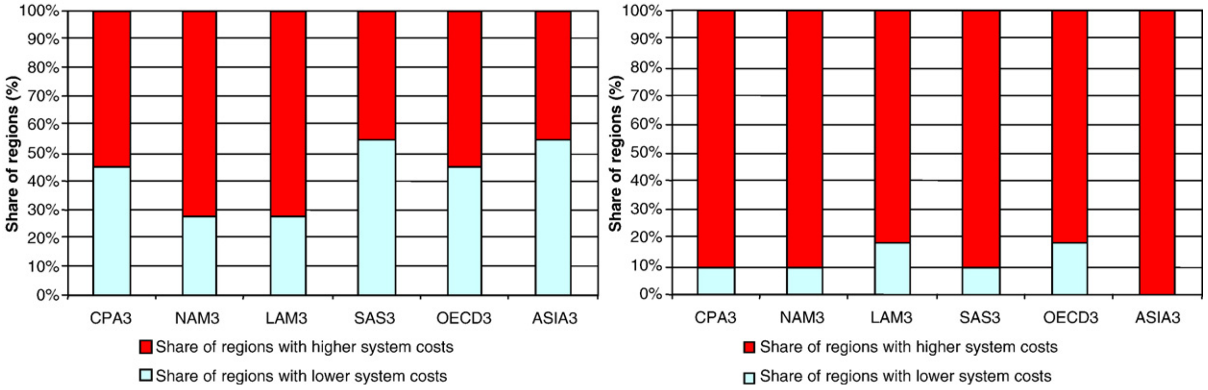

Fig. 8. Share of regions with higher or lower non-discounted cumulative system costs in 2030 (left panel) and in 2100 (right panel). Reference level is scenario A2r-660.

shown in the right panel of Fig. 7. Scenario NAM3 also has lower reductions during the first three decades, but since it also has total system costs close to those of A2r-660, no such peak in average mitigation cost is experienced. In general, we observe that longer durations of non-participation of regions lead to consistently higher increases in global mitigation costs as well as higher cost peaks, which are caused by the increased efforts of other regions. Even after a region joins the mitigation scheme, annual system costs remain higher than in the global participatory scenario. This is important as it signifies that non-participation of key actors in climate regimes, even if only temporary, implies substantially higher mitigation costs and lower emissions reductions until the end of the mitigation scheme.

Non-participation can also considerably affect regional costs through the redistribution of mitigation measures, changes in trade flows and other structural changes. However, to evaluate completely the regional effects fully requires that a burden-sharing scheme be established, since emissions trading and the financial flows can play an important role in defining such costs [10]. Since we did not define any regional caps on emissions and therefore have no explicitly modeled emissions trade flows, it is difficult to fully analyze regional costs. We can, however, make some general observations concerning the development of the costs paid in a given region, even if we cannot tell who pays these costs.

The left panel of Fig. 8 indicates that non-participation of a region does not necessarily imply an increase in costs in the short term for all regions. Some regions even experience lower costs. This is to some extent, of course, dictated by our assumptions on perfect foresight and the possibility to postpone emissions reductions globally. However, we observe that in the longer term (i.e., by 2100), almost all regions have higher system costs than in scenario A2r-660. This reiterates that, although in the short term the effects, especially regional effects, can be ambiguous; in the long term, non-participation of a region indicates much higher overall costs of mitigation for most regions.

The results shown in Fig. 8 already indicate that increases in costs are likely to be a closely related to the cumulative mitigation activity of the non-participating region in the full-efficiency case. Fig. 9 shows system cost differences compared with the baselines as a function of carbon lost through non-participation.[9] The higher the lost mitigation efforts through postponement of participation of a region,

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[9] Defined as the cumulative difference in emissions of the non-participating region compared with the full participation scenarios until the cut-off time (2030 or 2060).

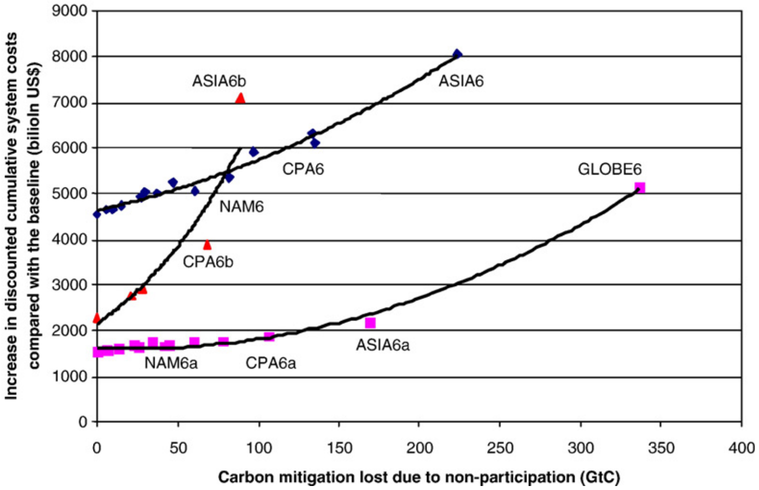

Fig. 9. Cost of mitigation as a function of cumulative carbon mitigation lost through non-participation for the full range of scenarios: climate targets 510 (triangles, B1 baseline), 660 (diamonds, A2r baseline) and 850 ppm CO_2-eq (squares, A2r baseline).

the greater the costs of the climate regime. The stringency of the climate target together with the respective baseline defines how sensitive these cost increases are to regionally delayed participation. We observe that the A2r-850 scenario exhibits a lower cost increase compared with the A2r-660 scenario for the same amount of lost mitigation. This is because the stringent target in the A2r-660 scenario implies that a large share of the mitigation potential has to be tapped to meet the target and any loss of potential through non-participation of a region increases costs quickly. This effect is also clearly demonstrated by the stringent mitigation case B1-510, in which costs very rapidly increase with mitigation lost.

Another interesting observation is that sometimes a slightly higher amount of mitigation lost does not automatically lead to higher costs. This indicates that there are differences between the mitigation potentials of regions not only quantitatively, but also qualitatively (i.e., some regions are able to increase their mitigation without increasing the costs significantly, while many others do not have this untapped relatively cheap mitigation potential).

4. Conclusion

In this paper, we analyze how delayed participation by regions can affect a long-term international climate mitigation regime. We compare and contrast an optimal climate strategy that assumes all regions contribute to mitigation efforts versus one in which particular regions opt to stay out for a certain period of time. Our approach is a scenario-based sensitivity one that imposes limits on the spatial and temporal flexibility in mitigation responses to capture fully the effects of 'incomplete' regional participation. Our analysis shows that such non-compliance can have far-reaching effects on the spatial and temporal distribution of mitigation efforts, on the development of energy infrastructures and on the estimated mitigation costs.

Delayed participation of a region generally leads to either a postponement of global emissions reductions or increased mitigation efforts by the participating regions. Of these two strategies, postponement is more common when the length of the non-participation period is shorter; and to achieve targets remains feasible even when a large emitter like China remains outside the climate mitigation regime for the next three decades. If non-compliance with the climate regime lasts over 50 years, more mitigation efforts are 'lost' and the global postponement of emissions reductions can mean that the target cannot be reached and therefore the strategy in which emissions reductions are redistributed across the participating regions is favored.

The clearest and most pervasive conclusion considering the energy infrastructures, especially for scenarios based on the fossil-heavy baseline A2r, is that the use of coal, especially in the electricity sector, is greatly increased through non-participation. Although this occurs in the region that does not participate in the mitigation regime, the effect perpetuates to the global level. In the non-participating region, this large investment in conventional coal technologies creates a large inertia in the energy system. This prevents the region from quickly moving into a more carbon-free energy-production portfolio after it has rejoined the mitigation regime. It takes several decades to overcome this inertia caused by the regional postponement of participation.

We find that, over the full century, non-participation always leads to an increase in mitigation costs on the global scale-emissions reductions that were not made during the time and in the region where they would have been optimal have to be redistributed and abated using options that lead to higher mitigation costs. The average cost over the century for a ton of CO_2 mitigated can increase as much as 40% because of the non-comprehensiveness of the mitigation regime. The extent of these additional mitigation costs depends on the significance of the non-participating region (in terms of mitigation potential) and therefore on the extent of 'lost mitigation', but also on the climate target and on the underlying baseline. These results illustrate the importance of both the baseline and the target as indicators of the flexibility available for redistribution of mitigation.

In general, our results stress the significance of establishing international climate regimes that involve a large number of players from the beginning. Regionally incomplete regimes lead to additional mitigation costs and delays in technological transitions and can thus prove inefficient and potentially harmful in the long run.

We conclude with some methodological notes and suggestions for further work. Mitigation analysis so far has tended to focus on all-efficient mitigation regimes, in which regions either contribute fully from the beginning or in which a burden-sharing scheme is used and regional time-dependent caps allow delayed action by some regions. We present here an initial step toward including some uncertain aspects of climate agreements in the mitigation analysis by using a more flexible approach, in which mitigation measures are redistributed across time periods and regions because of the non-participation of a region. While we do not include any burden-sharing scheme here, which thus renders regional cost calculations incomplete, to account for the monetary flows from the trade of emissions permits would not alter our results in any way, except altering regional costs. Given the complexity of the issues, further techniques, like agent-based modeling, more complex regional participation strategies, or the use of limited foresight, could prove useful for broadening the analysis of the effect of regional non-participation in climate-mitigation regimes beyond the sensitivity analysis presented here.

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Appendix A. Indicators for the scenario runs

	Total greenhouse gas emissions (Mt C_{eq}/year)			CO_2 emissions (Mt C/year)			Primary energy consumption fossil fuels (Gwyear)			Primary energy consumption non-fossil sources (Gwyear)		
	2030	2060	2100	2030	2060	2100	2030	2060	2100	2030	2060	2100
A2r-660	12,934	9941	6838	10,580	7073	3294	16,329	20,662	29,812	6475	16,668	30,453
CPA3	14,184	9450	6551	11,414	6632	3002	17,259	20,376	29,862	6331	16,922	30,641
CPA6	13,118	12,572	5791	10,409	9039	2304	16,624	22,996	29,245	6610	16,634	31,005
LAM3	13,198	9870	6749	10,766	7017	3198	16,649	20,519	30,027	6211	16,784	30,418
LAM6	12,823	10,552	6693	10,445	7642	3130	16,369	21,502	29,825	6369	16,768	30,739
NAM3	13,648	9717	6594	11,129	6883	3050	17,023	20,500	29,787	6353	16,798	30,635
NAM6	13,019	11,569	6305	10,590	8523	2790	16,670	21,757	29,587	6470	16,530	30,779
SAS3	13,317	9804	6758	10,807	6958	3212	16,367	20,562	29,987	6451	16,760	30,421
SAS6	12,859	11,323	6404	10,414	8088	2893	16,257	20,682	29,446	6464	16,751	30,861
OECD3	14,205	9461	6523	11,619	6646	2980	17,457	20,469	29,817	6270	16,863	30,658
OECD6	13,772	12,638	5672	11,167	9451	2159	17,432	22,753	29,886	6268	16,542	30,908
ASIA3	15,020	9195	6453	11,985	6389	2907	17,774	20,398	29,700	6008	16,998	30,789
ASIA6	13,340	15,150	4795	10,386	11,224	1364	17,150	23,418	28,474	6684	16,558	31,418
GLOBE3	18,535	8,390	5,937	15,095	5,621	2378	17,500	20,040	30,170	6063	17,467	30,807
A2r-850	15,093	15,071	11,276	12,580	11,949	7777	17,932	22,152	27,215	5599	14,916	28,181
CPA3a	16,217	14,922	10,869	13,299	11,805	7370	18,744	22,299	27,241	5252	14,898	28,436
CPA6a	15,917	16,688	10,010	13,026	12,973	6518	18,416	23,696	26,993	5518	14,568	28,838
LAM3a	15,298	15,125	11,190	12,712	11,993	7694	18,106	22,201	27,226	5436	14,907	28,270
LAM6a	15,187	15,621	11,056	12,610	12,424	7537	17,966	22,831	27,441	5501	14,826	28,381
NAM3a	15,392	15,172	11,128	12,760	12,030	7632	18,149	22,396	27,053	5523	14,833	28,319
NAM6a	15,303	16,132	10,737	12,682	12,836	7247	18,084	23,269	27,396	5534	14,508	28,497
SAS3a	15,425	15,002	11,165	12,752	11,884	7672	18,012	22,136	27,163	5568	14,919	28,280
SAS6a	15,226	15,955	10,931	12,610	12,486	7437	17,914	22,481	27,066	5620	14,794	28,411
OECD3a	15,809	15,045	11,027	13,073	11,903	7541	18,466	22,394	27,068	5386	14,849	28,390
OECD6a	15,614	16,481	10,420	12,915	13,081	6958	18,343	23,821	27,208	5481	14,355	28,718
ASIA3a	16,810	14,690	10,712	13,644	11,581	7218	19,021	22,188	27,060	5095	14,964	28,551
ASIA6a	16,375	18,399	8833	13,249	14,206	5469	18,659	24,540	26,871	5422	14,338	29,742
GLOBE3a	18,535	14,144	10,487	14,975	11,067	6998	18,808	21,848	27,258	5181	15,171	28,633
GLOBE6a	18,535	28,007	4814	14,882	23,170	1426	20,094	27,335	27,098	5037	13,971	32,552
B1-510	8308	2546	1781	6249	494	6	13,135	8184	5160	8508	18,710	17,514
CPA3b	8724	2400	1770	6305	369	5	13,172	7516	4676	8589	19,259	17,829
CPA6b	7616	4011	1738	5371	1586	0	12,327	8233	3325	9301	18,922	19,087
ASIA3b	8894	2368	1765	6330	339	5	13,276	7256	4286	8552	19,459	18,154
ASIA6b	7390	4879	1717	5235	2195	0	11,727	6451	2532	9816	20,222	19,879
GLOBE3b	12,928	1809	1706	6756	27	0	12,657	3450	1959	9605	23,268	20,763

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