National Soft Landing CO2 trajectories under global carbon budgets

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ÉCONOMIE DU DÉVELOPPEMENT DURABLE
ET DE L'ÉNERGIE

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1. Introduction

The installation of an international climate regime is a complex and difficult process. After the failure – compared to expectations – of the 16th Conference of the Parties to the UNFCCC in Copenhagen, the main outcome of COP-17 has been the Durban Platform for Enhanced Action. There, the Parties have decided to launch a new negotiation process in order to develop a *"protocol, another legal instrument, or agreed outcome with legal force,"* addressing the post-2020 period and *"applicable to all Parties"*. While the form of this new "instrument" gives way to many suggestions, our concern in the present paper is directed towards the content of this potential instrument. As a matter of fact, the absence of discussion about the content of the future commitments makes some countries reluctant to rally to the process. Moreover, the content of the agreement will structure and determine its form. In any case, the decision to keep the 2°C temperature increase as a reference and the mention to the *legal* form indicates that we may head for a combination of a top-down agreement and of national bottom-up contributions to reduce GHG emissions.

Therefore, the post-Kyoto question of how to allocate a global carbon budget or how to share the burden in emission reductions gives way to a new one, which is: how to reconcile the above-mentioned national approaches with a consistent international perspective? In other words, how to produce a better alignment of national policies with global requirements? This paper proposes a harmonized "Soft Landing" approach that aims at developing of a common benchmarking tool for national emission reduction policies. The Soft Landing scheme was first proposed by Criqui and Kouvaritakis back in 2000 and initially developed as an international commitment scheme for a climate arrangement (Blanchard, Criqui *et al.* 2000). The scheme proposes a set of national trajectories based on smoothed profiles for yearly emission variations. The emission trajectories and variation profiles are differentiated on the basis of one mixed indicator of *capability* (per capita income levels) and *responsibility* (per capita emissions).

The approach is meant to be transparent because it is based on easily observable and relatively undisputable variables. It is also meant to be straightforward and robust as it avoids any abrupt change in the rate of emission variation along time. The transparency feature lays in the fact that the emission trajectory is designed not to impose a target to each Party but precisely to provide the needed framework for the benchmarking of national bottom-up abatement plans. We argue that the Soft Landing scheme provides a practical approach in order to reconcile the will of most Parties to propose bottom-up plans to emission reductions and the necessity to make these proposals compatible with a collectively acceptable global pattern, i.e. an aggregate emission pathway that is consistent with the 2°C target.

In section two, we briefly outline the main pillars and the latest developments which emerged in the UNFCCC negotiations concerning the design of the climate regime. We will focus on the most recent UNFCCC meetings in order to give a perspective which will enable us to analyze the key elements of the Durban agreement in an attempt to point out how these developments can become ethically acceptable, and economically and politically feasible (Olmstead Stavins, 2010). Then, we will "crystallize" this perspective and formulate some principles which might be seen as anticipatory of the negotiation process and of the main associated difficulties. Our proposal corresponds to a revisiting and updating of the Soft Landing approach, with the goal of using it, not as a burden-sharing tool but rather as a benchmarking and assessment tool. The integration of this scheme in a broader perspective will lead us in the third section to the introduction of the REDEM (REDuction of EMissions) software for the simulation of Soft Landing scenarios. At this point we will present the model, the key parameters and the rationale of the proposed choices of hypotheses and relations. In the fourth section, we illustrate our proposal and implement this toolbox for three simulation exercises. The last and fifth section will bring forth the relevance of the results and their adequacy to the building of a future climate agreement. We then conclude by a brief synthesis of what this approach may bring to the process of building a new international climate regime.

2. From burden-sharing to coordinated soft landing trajectories

21. Recent developments in the institutional design of the international climate regime

The "narrative" of the climate change regime architecture goes back to 1992. It begins with the Convention text containing the principles and the rules that are meant to shape a climate regime in order to achieve its ultimate goal, the stabilization of the GHG in the atmosphere (article 2). The next article introduces the principle of "common but differentiated responsibilities and respective capabilities" and establishes a distinction between the Annex I (developed countries) and the non-Annex I (developing countries) (United Nations 1992). Later on, as an application of this principle, the Berlin mandate (United Nations 1995) specifies that the Annex I countries are to adopt a protocol which in fine will lead to emission-reduction targets.

However, as noted by Stavins and Aldy, this distinction drives to "a greater emphasis on *differentiated responsibilities* than on *common responsibilities* and little consideration of *respective capabilities*" (Aldy, Stavins, 2012). This imbalance in dealing with the Convention principles seems to have driven the discussions until the late 1990s, when the bulk of the CO_2 emissions (around 60 %) and the ability to abate them still came from the AI countries. After the financial Asian crisis (1997-1998), and a dramatic macroeconomic adjustment, economic growth gets back on track and the emissions of the main emerging countries followed. By 2003, the GHG emissions of the non AI countries overcome those of the AI countries. During that period the GHG emissions of the non AI countries have progressed by two thirds, while the AI countries' GHG emissions decreased slightly (Criqui, Ilasca, 2010)[1]. This clearly sets a new perspective for the assessment of responsibilities and capabilities.

[1] The NAI countries took the lead in the CO_2 emissions from fuel combustion a few years later, by 2008. (Source: IEA, 2012).

With regards to the UNFCCC process, the current negotiation round was launched in 2005, in Montréal, with the Parties establishing the AWG-KP in order to pursue the decision process within the Kyoto Protocol after the first period. Meanwhile, the Kyoto Protocol came to show its limitations: at that time, it concerned less than a third of the world's CO_2 emissions and a relatively short period of time (five years, between 2008 and 2012). Thus, a second working group, the AWG-LCA was established in Bali (2007), which involved all the countries, and which was meant to deal with the long term actions, dealing with the remaining two thirds of the CO_2 emissions[2]. In fact, since then, in the NAI countries CO_2 per capita emissions have progressed by more than 10%, while they remained stable in most AI countries, but at a level that is three times higher[3] (IEA 2012).

By 2009, during the 15th Conference of the Parties in Copenhagen, the expectations were significant, while the two working groups were expected to deliver their results. The main points were related to the second period of the Kyoto Protocol and the major emitters, which were supposed to join the effort of emission reduction. For the first time, the developing countries stepped forward to join the main emitters in the limelight. Even with some positive outcomes – EU having a conditional pledge of 30% emission reduction, the US House of Representatives passing a climate bill (ACES) that would reduce their emissions by 17% below 2005 level, by 2020, or even China and India adopting carbon intensity targets – they were not enough to deliver a strong result: "capturing these national policies in an international agreement has proven extremely difficult" (Bodanski 2010). Copenhagen in the end deceived the expectations.

Later on, in the Cancun-Durban sessions, the bottom-up approach to mitigation was confirmed. The Kyoto Protocol managed to survive, but the withdrawal of Japan, Russia and Canada gave it a rather "symbolic" value. As a matter of fact, the Copenhagen Accord gained more importance since it had stronger support (some 140 signatures) and covered almost 80% of the global GHG emissions. That means that the "center of gravity" of the mitigation actions was moved in the Convention area (precisely in the LCA group discussions), which is consistent with the adoption of the bottom-up approach. The Durban Conference, through the Durban Platform for Enhanced Action (ADP), depicts the compromise between the EU commitment for a second period on the Kyoto Protocol and a timetable meant to lead to a "legal instrument or agreed outcome with legal force" by 2020 for all countries (Diaz *et al*. 2012).

The Durban Platform is the first Decision adopted by the COP body (passing through the Convention track (LCA)). The second decision, as an outcome of the AWG-LCA, is more consistent and specific and introduces key elements regarding the future regime. Both Decisions contain essential points which should be addressed in order to have not only a scientifically,

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[2] By 2010, this ratio of the CO_2 emissions was 25% from the Kyoto Parties and 71% from the US and the NAI countries. The difference to 100% came from the international marine and aviation bunkers.

[3] Even within the NAI group, the disparities were very important, varying from virtually zero t/capita to more than 30 t CO_2/capita. In fact, in 2007, more than ten NAI countries had higher emissions per capita than the EU.

economically and politically reasonable agreement, but also a comprehensive one, based on equity. Thus, the second paragraph of the Durban Platform recognizes the emission gap and mentions the 2°C target. Further down, reference is made to the fact that a plan is needed to identify the actions to close this gap by means of the highest possible mitigation efforts and by all Parties. Concerning the mitigation efforts to be taken by the developed countries, the COP decides to continue the process of clarifying the quantified emission reduction targets (an aspect which was not clarified in Warsaw). Regarding the developing countries, the Parties do not "decide" as was done for the AI countries, but just "invite" NAI countries to submit further information on their actions.

Whatever the protocol, legal instruments or agreed outcomes with legal force will come from the negotiations by 2015 and should contain key elements taking into consideration the UNFCCC broader process, as well as the latest Conference Decisions. This new accord has to include, from the economic and ethical perspectives, a differentiation criterion that doesn't violate basic equity principles in emission reduction, a regulatory approach which may provide a reasonable chance to reach the 2°C target and clear indications on the comparability of the countries' mitigation efforts.

More recently, the discussions regarding the ADP process are structured by two work streams (Decision 2/CP 18). The first one aims to develop key features of the next accord, among which science, equity, flexibility, effectiveness and the participation according to national circumstances. The second work stream concerns the options to close the remaining emission gap. The fulfilment of a post-2020 accord depends on how it can manage to bring together, strengthen and coordinate these different key elements. However, at this point, there are disagreements on many issues: the regulatory approach, the equity dimension (differentiation of commitments), the ambition level for reductions and the legal form (Bodanski 2012; De Vit & Hohne 2012), all of which are understood differently by the Parties.

In other words, the next climate Accord should be able to combine the bottom-up approach, which is necessary but not sufficient (when added up, the actual national pledges lead to a 3-4°C warming of the temperature; Vieweg *et al*. 2013) and the top-down rationale, which is desirable but for the moment hardly feasible . If we consider that the art of politics is, according to Michel Rocard a former French PM, to "make the desirable possible", then we should start by identifying, within climate discussions, a manner to reconcile the above-mentioned principles.

2.2. Reconciling bottom-up realism and top-down consistency

In that perspective, the reasonable thing to do is to find practical ways to solve this dilemma, which is necessary for the enabling of the Convention's main objectives. Some features are expressed in the Parties' positions as well as in the latest developments of the discussions within the ADP process. These proposals might be summarized as follows:

- The objectives must be differentiated, according to the CBDR principle, based on the countries' responsibility; the differentiation should be "continuous" and not by affiliation of countries to different groups or "clubs"; the once considered Multi-Stage approach (Den Elzen *et al*. 2003), based on different country categories, indeed may pose huge political acceptability problems.

- The reasoning should be based on the simplest as possible set of easily observable and non contestable variables (population, GDP, emissions) in order to develop differentiation indicators and benchmarking profiles that could be least subject to controversy.
- The national pledges, formulated in a bottom-up manner, should not be leading to an externally imposed emission level; the transparency and comparability of the national decarbonisation plans should be ensured through common accounting rules in an international benchmarking system.
- This benchmarking system should be compatible both with the bottom-up and the top-down perspectives. As a matter of fact, the "hybrid approaches" gain increasing traction in the UNFCCC talks (IISD 2013); more precisely, it should show either the coherence or the discrepancy between the national and the global emission profiles, with the final goal of *achieving a better alignment of national perspectives with the global target.*
- The differentiating system should be based on a sound economical perspective that ensure in particular that no shock is imposed to the national economies through emission reduction targets; such is the case of the South African « Peak, Plateau and Decline » proposition, which enables a smooth profile for the mitigation efforts to be undertaken nationally (Yawitch 2009).
- The scheme should be submitted to a transparent measurement and verification process in order to ensure the convergence of the emission reduction efforts towards, after aggregation, the 2°C target.

In sections three and four below we propose a benchmarking tool that is designed to fulfil these underlying principles. Our approach is based on the original Soft Landing proposition, made by Criqui and Kouvaritakis in the early 2000. We develop an up to date solution which improves the original idea mainly by introducing common but dedifferentiated emission reduction profiles and by developing a dedicated algorithm for that purpose (henceforth called REDEM).

The differentiation indicator we propose to use is a simple combination of each country's per capita emission and per capita GDP. The per capita emission can be considered as reasonable proxy of a country's responsibility, and the per capita GDP a measure of its capacity for action. In the following, we call this indicator, the CRI (Capacity-Responsibility Indicator) and discuss its definition and properties.

To be compatible with global objectives, it is commonly accepted that for most developing regions, the national emission curves should admit a maximum – a peak, possibly prolonged by a plateau – and then should progressively decline. Similarly, we emphasize the fact that, in order to achieve the global objectives, all states will have to entail mitigation efforts, the intensity which may be measured by the rate of variation of the national emissions. At one point, the effort will reach a maximum, when the rate of variation in absolute value is at its maximum, and then decrease. In other words, there will also be a peak in the effort. Hereafter, we propose to base the benchmark on this peak of effort. In the following sections we detail the criteria used to define the peak of effort, in a common but differentiated way and then introduce it in REDEM.

2.3. Soft Landing approach with "peak-plateau and decline in emissions" rationale

The Soft Landing approach was first proposed back in 2000 and the rationale was meant to allow countries – especially the developing ones – to slow down the increase and then decrease their emissions (Blanchard, Criqui *et al*. 2000). In their original assumptions, the authors proposed reduction targets for the Annex I countries and stabilized emissions by different dates for the developing countries. The main criteria for differentiation, besides the distinction between Annex I and non-Annex I, depended on the ability to pay (as measured by their per capita income) and their actual causal responsibility (as reflected by their per capita emissions).The intended time frame was 2030 and the level of CO_2 concentrations in the atmosphere was 550 ppmv, based on the IPCC stabilization scenarios.

The scheme was used again in 2003, in the Greenhouse Reduction Pathways study for DG Environment (Criqui *et al*. 2003). The differentiation criteria were synthesized in a composite indicator, the Capacity Responsibility Index (a simple summation of emissions per capita and GDP per capita). The study covered the period up to 2030, period extended later on to 2050, based on the POLES model results (Russ, Criqui 2007). Naturally this was a rather ad hoc indicator, but from a dynamic and long term perspective, it turned out to be simple and adapted to the purpose of differentiating the targets according to the combined responsibility and capacity of the different countries to deal with climate change mitigation.

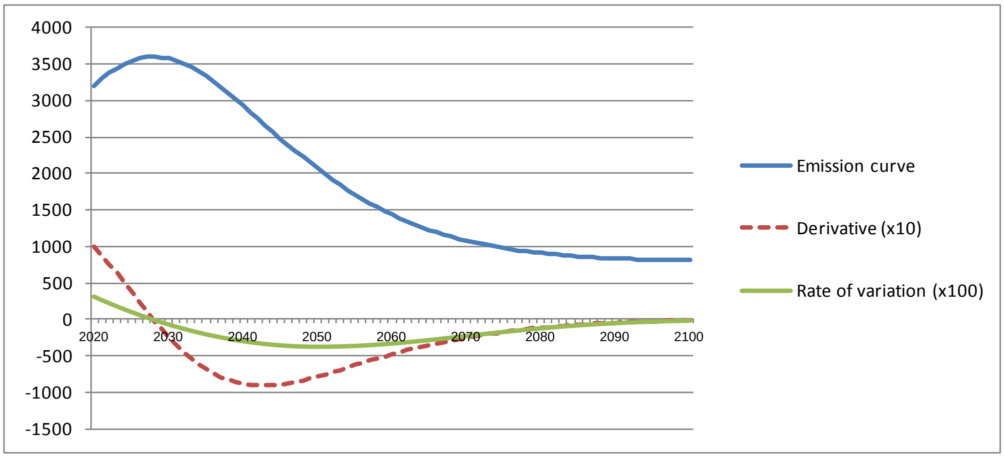
Indeed in the early years of its development, the Soft Landing approach has been characterized by the taking into account of the Convention principles: stabilization of the emissions in the medium term (before 2030), differentiation of commitments and comprehensive participation. As the authors themselves wrote at that time, and since "the world emissions should ultimately decline" (Blanchard *et al*. 2001, p.15), we might consider the Soft Landing approach as an "early release" of what South Africa proposed in 2009 as its mitigation strategy: a *peak-plateau-decline* benchmark emission trajectory.

Since the early 2000s indeed, a tremendous growth in emissions have been triggered by energy consumption, driven by economic and demographic growth, so as by the choices of energy technologies and primary sources (EIA 2013). Most of these factors have taken place and are expected to continue in the emerging countries. The corresponding trend of sustained emission growth will continue as long as the emerging countries will be in a rapid catch-up dynamics. Meanwhile, the stabilization and decrease of emissions is not only required from a global perspective, but also conceivable based on a growing willingness of emerging nations to limit the domestic impacts of climate change and of the use of dirty fossil fuels. Therefore a *peak plateau decline* scenario type seems logical if we picture the aggregate trends of the CO_2 emissions. Thus, the rationale behind the peak plateau decline emission pathway can be easily conceived. We may consider that the "increase/peak" is required by a developmental agenda, the "plateau" can be justified by the energy infrastructure inertia (Jaccard, Rivers 2007; Davis *et al*. 2010), while the "decline" could be explained, as mentioned, by the sustainability raisons.

3. Description of the REDEM approach and algorithm

We now detail the REDEM software, as a tool designed for the benchmarking of national emission reduction trajectories. One of the characteristics of REDEM is that it principally focuses on the rate of variation of GHG emissions, even if it also fully considers emission profiles and total emission budgets for the period considered. In addition, REDEM is based on the fundamental observation that when emission curves follow the "Peak, plateau and decline" pattern with a final stabilization at a low level, the rates of emission growth 1) decrease, then 2) reach a minimum and then 3) slowly increase and converge to zero (see Figure 1).

Figure 1: Emission curves and rate of variation curves for typical "Peak, plateau and decline" trajectories



Note: "Peak, plateau and decline" emission profile in blue, first derivative with red dotted line (x10) and rate of variation of emission or decarbonisation rate (x100) in green

Contrary to previous proposals that in some sense concentrated attention on the peak of emissions and the zero crossing of emissions growth rate, we focus here on the peak in the rate of reduction of emissions, or decarbonization rate. This peak – indeed rather a trough – takes place later than the emission peak, and can be interpreted as a peak of effort. It is then of huge significance since it allows measuring and comparing the maximum effort that states have to make during the period. The fact of considering this peak allows exploiting in a simple and relevant manner the differentiation indicator mentioned in the previous section. We indeed propose to parameterize the maximum effort for each of the states according to the above-mentioned capacity-responsibility indicator in a "proportional" way. By doing so, we then naturally obtain a common benchmarking method which proposes differentiated objectives based on a simple indicator. In addition, the algorithm in REDEM is designed in order to compute emission curves for all the countries in such a way that the global aggregated emission budget is consistent with the chosen temperature target (for example, the 2°C climate target).

3.1. The Capacity-Responsibility Indicator

As mentioned above, we propose to design the differentiation indicator based on the simplest and most easily observable variables that reflect the responsibility of the states in global warming and their abilities to act. We then propose to base it on the per capita emissions e_i (for the responsibility) and their per capita GDP p_i (for the capacity to act) at a fixed date; the i indices corresponding to the indices of the considered states.

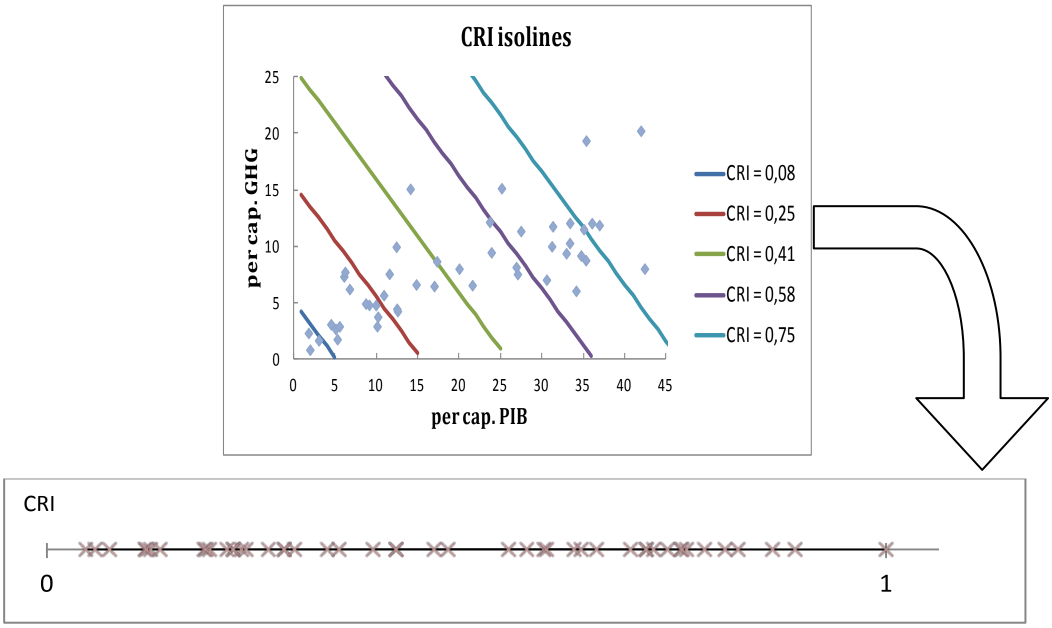
In practice, we suggest fixing the reference year in 2010 and this is what we have done in our simulation exercises. Drawing on what has been proposed above we use as differentiation indicator the following normalized and weighted sum and define what we call the Capacity-Responsability Indicator (CRI):

$$CRI(i) = (r\ p_i + e_i\ ) / \delta$$

where the parameter *r* weights the relative importance of the capacity component versus the responsibility component, and where δ is the maximum value of the $r\ p_i + e_i$ over all the states *i*. Parameter δ allows to normalize the indicator in such a way that $CRI(i) \leq 1$ for all *i*, and that there exists a state i_{max} for which $CRI(i_{max})=1$..

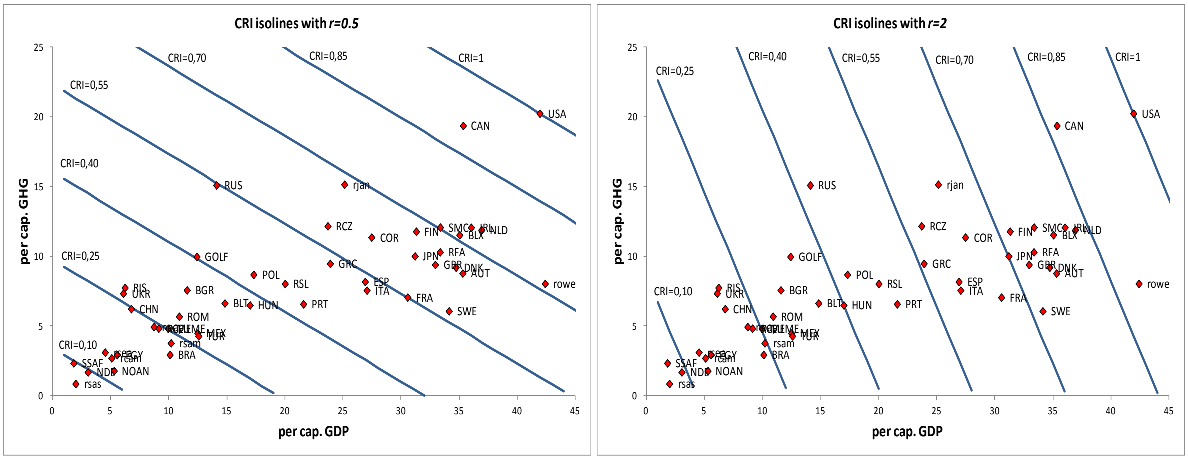
As illustrated by Figure 2, the CRI then allows to project the 2-dimensional distribution of state indicators (p_i, e_i) to a 1-dimensional distribution included in the range [0,1]. In this figure, the oblique lines correspond to the CRI isolines (or level sets). One point or cross corresponds to a state.

Figure 2: From the 2D distribution of (p_i, e_i) indicators to the CRI indicator



The parameter *r* is important parameter and must be carefully considered. Figure 3 illustrates the impact of this parameter on the repartition of the indicator. For example, for *r=0.5*, Russia has the same CRI as France or Sweden, when, for *r=2*, Russia has the same CRI as Poland. For *r=0.5*, Canada has a much bigger CRI than ROWE (Rest of Western Europe), while for *r=2*, the situation is opposite. USA has the maximal CRI; as a consequence its CRI is equal to 1 (because of the normalization).

Figure 3: CRI isolines for *r=0.5* and *r=2*



3.2. Principles and parameters in REDEM

Date parameters

Let us start with the time parameters, period and date. The whole period considered extends from 2000 to 2100. In particular the GHG global emission budget is computed on this period (in order to get the consistency with temperature target). Then two key date parameters need to be considered. The first one is the date when it is assumed that the BAU trajectory will be abandoned for following the "Soft Landing" one. In the following, we will denote this date: t_{SLS}. We propose to first assume this date is 2020. Note nevertheless that this date can be changed in the program interface and that its value can be fixed between 2010 and 2050. Between today and the t_{SLS} date, we propose to use emission curves from any BAU scenario, as modeled or given in national scenarios. In practice, we have used a Reference scenario produced with the POLES model in (Criqui, Mima 2012). The second date parameter corresponds to the "peak of effort" (i.e. the date of the maximum of annual reduction rate). For simplicity's sake, we propose that this date is identical for all countries. If required, this feature could possibly be modified; nevertheless we consider that such a modification may introduce an additional degree of complexity. In the following, we will denote the date of the "peak of effort": t_{peak}.

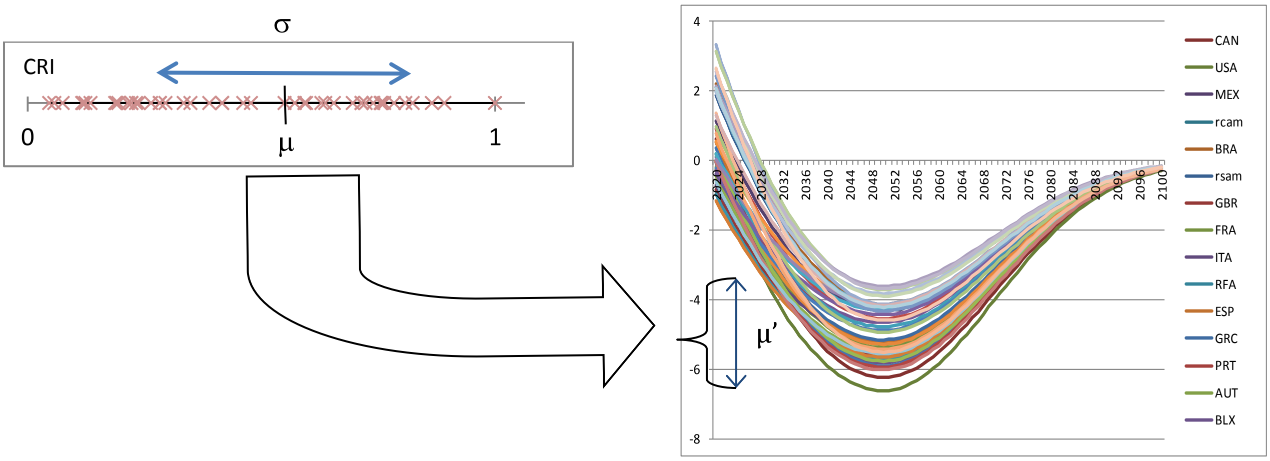
CRI parameters and adjustment factor ensuring the consistency with the temperature targets

As mentioned above, we propose to compute the maximum effort for each country according its CRI in a "proportional" way. To do that, we have to rescale and position the CRIs in an "effort" range. This can be done by a simple affine transformation of the CRIs; by changing their mean and their standard deviation; see Figure 4. The standard deviation σ' of the transformed CRIs gives more or less importance to these indicators. When σ' is fixed to zero, the maximal efforts are exactly the same for all countries. On the contrary, if σ' has a high value, then a state with a large CRI would be strongly penalized with respect to a state with a small CRI. Clearly, this scaling factor s' is an important parameter to be discussed.

Contrary to standard deviation σ', the mean μ' of the transformed CRIs is a parameter that is endogenously calculated in REDEM. The mean μ' is used as an adjustment factor. More exactly, μ' is computed by the algorithm in such a way that the global emission budget between 2000 and

2100 corresponds to the chosen temperature target. Here, the objective for the maximum increase in temperature (with respect to pre-industrial situation) is obviously a crucial parameter. The emission curves computed in REDEM are automatically consistent with the chosen objective.

Figure 4: Parameterization the maximum effort for each of the states with its CRI



Parametrization of the curves of the rate of variation

As mentioned above, our modeling effort focuses on the curves of the rate of variation of the emissions. This rate is defined by the derivative of the CO_2 emissions divided by the CO_2 emissions, and multiplied by 100 to get a percentage of variation. For all states, the proposed curve of rate of variation is a smooth curve which:

At date t_{SLS}, takes the value of the chosen Reference scenario curves at the same date (in other words, we consider the curves of rate of variation to be continuous at t_{SLS}).

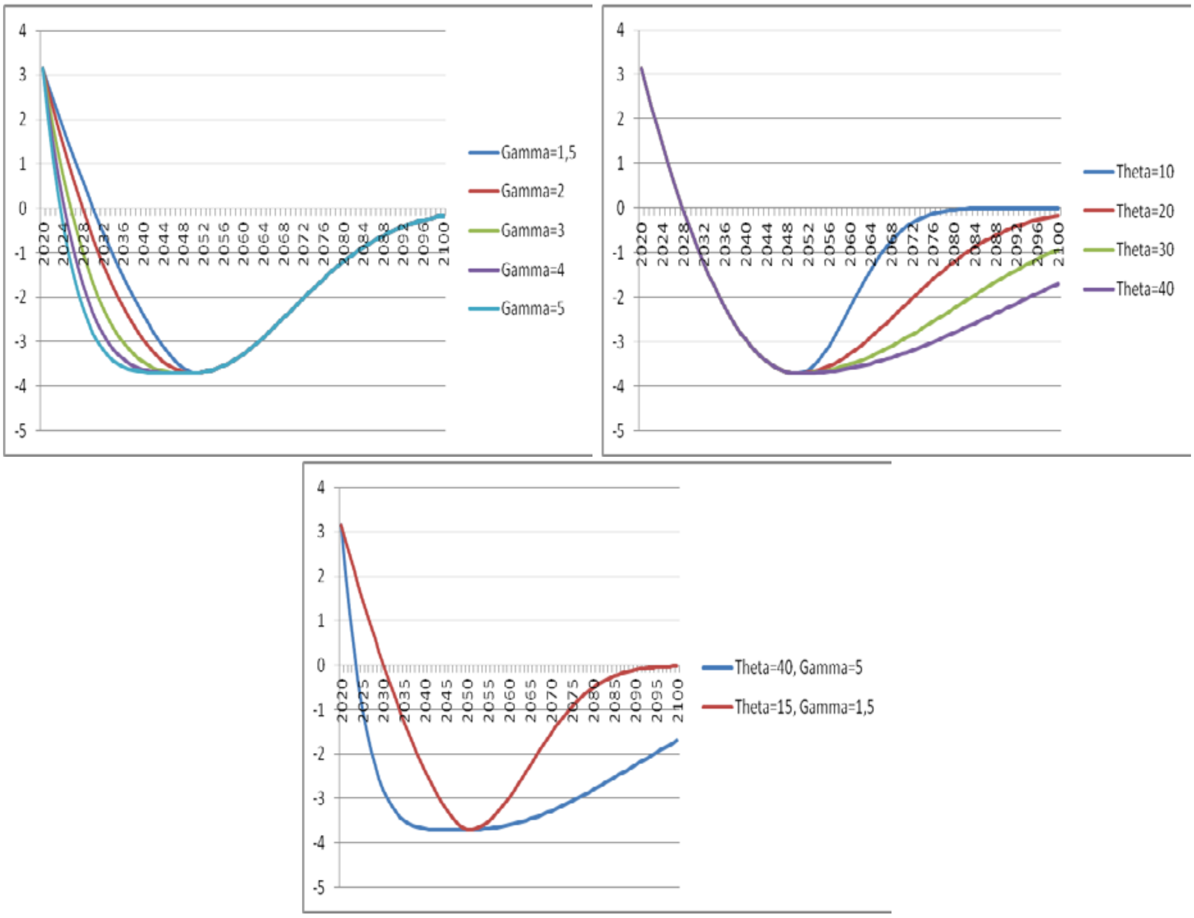
At date t_{peak}, takes the value of the associated transformed CRI (as mentioned above).

After t_{peak}, softly rises toward the zero value.

Between t_{SLS} and t_{peak}, the curves of rate of variation are defined by concave polynomial equations whose degree of convexity is parameterized by a parameter we denote γ. After t_{peak}, these curves are defined by a Gaussian function whose standard deviation parameter allows getting a more or less rapidly convergence toward zero. We denote this last parameter θ. See (Prados, Criqui et al, 2013) for the exact mathematical equations of the curves.

Let us note that we fix the parameters θ and γ to be the same for all countries. Only two parameters has thus to be exogenously set at this stage. These two parameters allow for example to get a more or less extended plateau for the curves of variation rate. Figure 5 illustrates the influence of θ and γ on the curves.

Figure 5: Influence of parameters θ and γ on the curves of the rate of variation

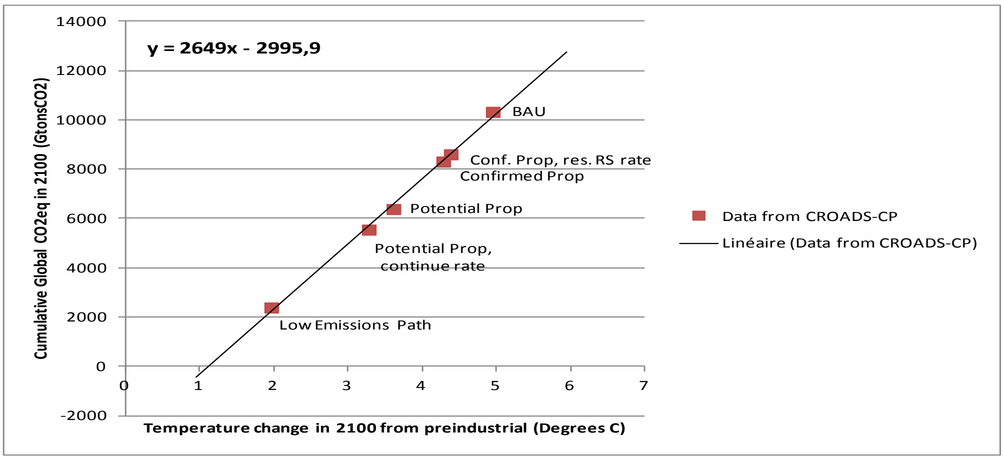


3.3. Relation between temperature change and cumulative global emissions

In the current version of the program, the conversion "cumulative global CO2eq emissions in 2100" (GtonsCO2) versus "temperature change in 2100" (from preindustrial, in degrees C) is given by an affine equation computed from the data provided by Climate Interactive via their CROADS-CP database[4]. This database provides the cumulative global CO2eq emission and the temperature change in 2100 for various scenarios named "Low Emissions Path", "Potential Prop", "BAU", etc. Figure 6 displays the obtained points for the various scenarios and clearly shows the linearity of the relationship. Of course, this relation can be very easily updated in our program by the user, if it is necessary.

[4] CROADS-CP v3.008, http://climatescoreboard.org/

Figure 6: Relation between temperature change and cumulative (1900-2100) global CO2eq emissions



In other respects, we think that a relation of the "cumulative global CO2eq emissions" with the "probability of limiting warming at 2°C" would probably be more appropriate for the discussion process. In (Meinshausen *et al.* 2009) such a relationship is demonstrated. Nevertheless, for the moment, this relationship is only available for a budget associated to the period 2000-2050 and not for the period 2000-2100 we consider here. However, because of its potential and symbolic interest, in the following we will refer to it for an illustrative purpose.

3.4. Output of the algorithm

When the parameters r, t_{SLS}, t_{peak}, σ', θ and γ are fixed, then the REDEM algorithm computes the emission curves for all the states (whose curves of rate of variation verify the parameterization defined above) such that the objective for the expected increase in temperature is verified (the temperature target being also indicated as parameter).

The actual version of the algorithm produces a set of curves: first it displays the curves of the rates of variation of emissions (in % per year), the emission trajectories, the emissions per capita, and a chart illustrating the distribution of the budget of emissions (budget between 2000-2100) for all states; see Figure 7. Then it shows the same curves for some aggregated regions (e.g. EU27 countries are aggregated). This allows getting a better comparison between the main regions of the world; see Figure 8. The interface allows also zooming on EU27 countries; as illustrated in Figure 9.

Figure 7: Examples of output curves for all states: rate of variation of emissions, emission trajectories, emissions per capita, distribution of the budget

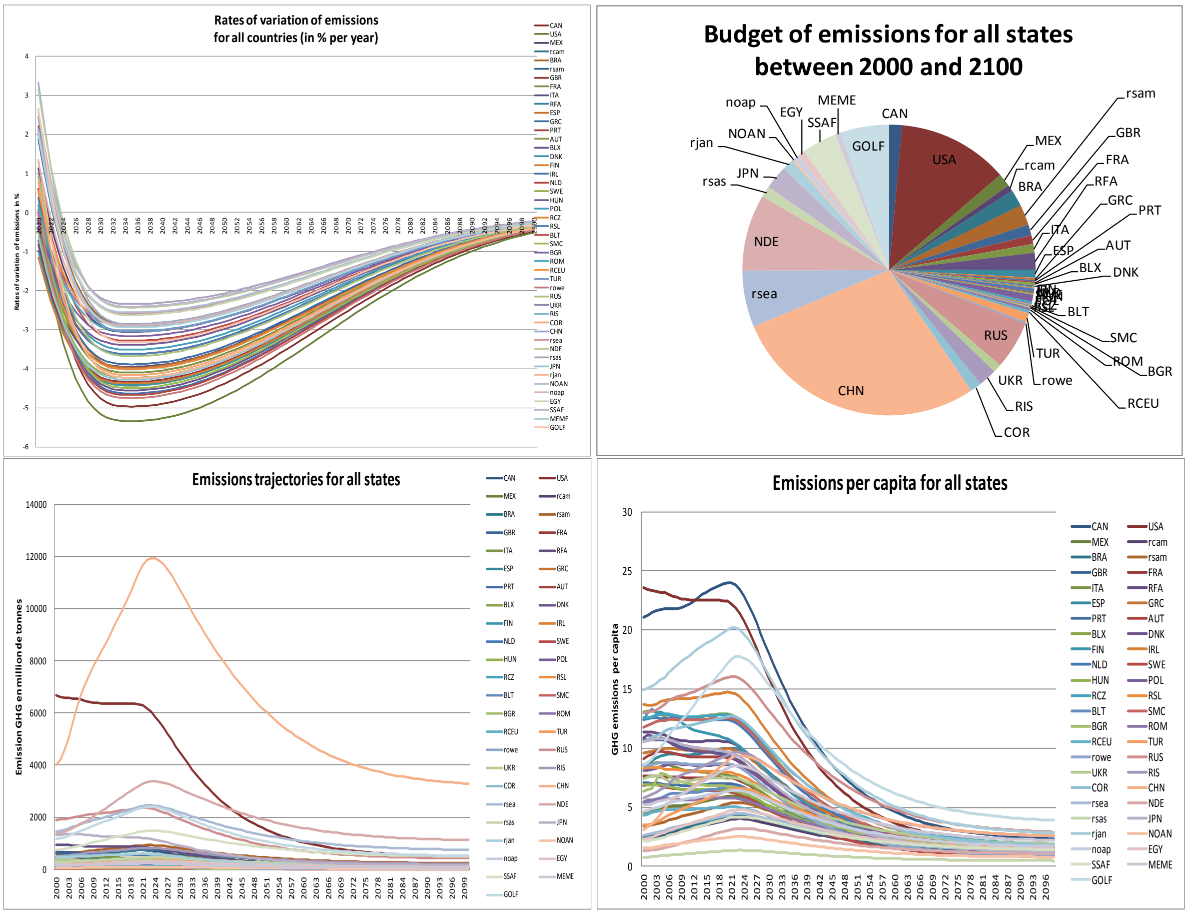


Figure 8: Examples of output curve for aggregated regions.

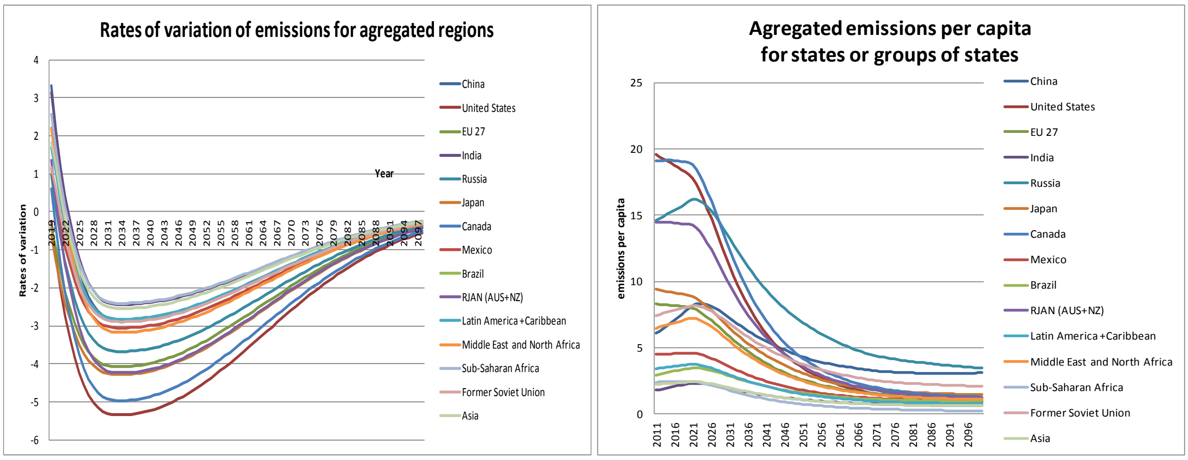
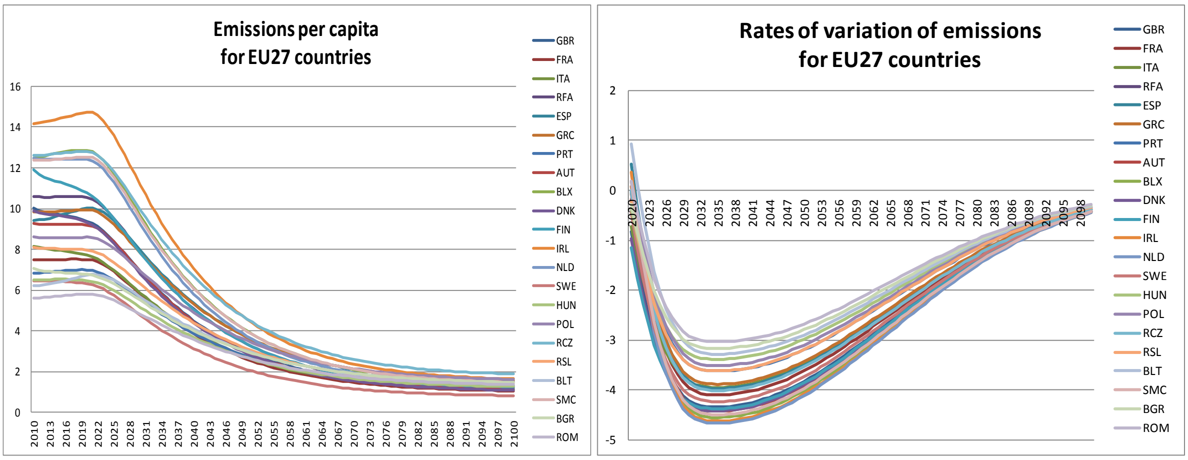
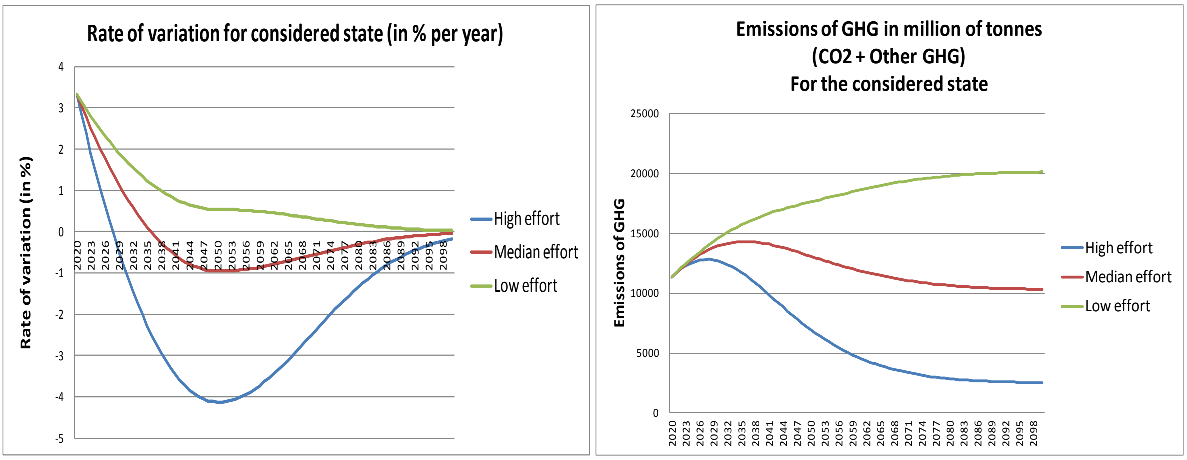


Figure 9: Zoom on EU27 countries.



Finally, it is also possible to get the rate of variation curves and emission curves of one specific state (e.g. France) obtained for several budgets on the same graph, as illustrated in Figure 10 (all the other parameters being fixed). This tool would thus allow to easily visualize "national decarbonisation corridors" which are globally consistent for all the states and verifying the rules mentioned in the previous sections.

Figure 10: From REDEM to national decarbonisation corridors.



4. Simulation examples

The core idea of the algorithm tries to answer a rather simple question: how can the convergence between the national pledges and the 2°C target be attained? What should the countries do and eventually what do emissions profiles have to look like in the long run? Taking into account the elements we have discussed above, we propose four illustrative ways to picture what we might call "effort profiles". The four scenarios that we exhibit depict different effort levels and cooperation options of the countries.

The scenarios are balanced between an "early" and a "delayed" action, from a high to a lower confidence in the emission stabilization and according to the importance given to the differentiation criteria. Such scenarios are characterized by changes of the values of the parameter t_{peak}, of the emission budget and of the differentiation parameter σ'.

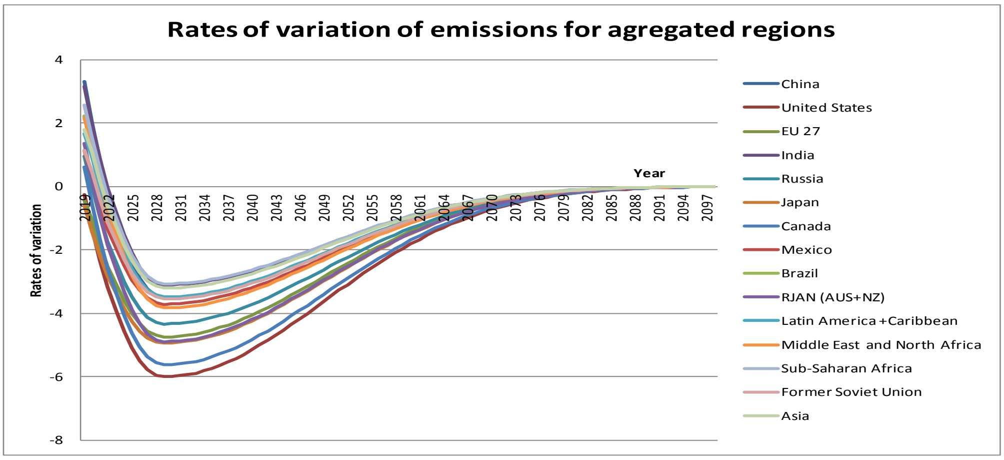
In the following simulations, all the parameters are the same as the ones used in the reference scenario (which is the first scenario) at the exception of only one parameter (which is a different parameter for each scenario). In particular, for all the above simulations, the starting date t_{SLS} (the end of the BaU simulation) is 2020, the *r* parameter is equal to 1 (*r* gives more or less importance to the capacity versus responsibility indicator), $\theta = 20$ and $\gamma = 2$ (parameters corresponding to the length of the plateau and the speed of convergence).

4.1. Early action, High Probability of limiting warming at 2°C (Bud.$_{1900\text{-}2100}$=2 302 GtCO2; t_{peak}=2030; σ'=0,8).

Our first scenario (which is then here our scenario of reference), called "Early action *hp*", has two main features. The peak effort is supposed to be attained in 2030 and the probability to limit the increase of global warming at 2°C is very likely (i.e. the total emission budget is fixed to 2 302 000 millions of ton of eqCO2). The standard deviation is σ'=0,8, a rather high value, which indicates that states with larger CRI are more discriminated than those with a smaller value.

Figure 11: Early action with high probability limiting the warming at 2°C.

Rate of variation of emissions between 2020 – 2100.



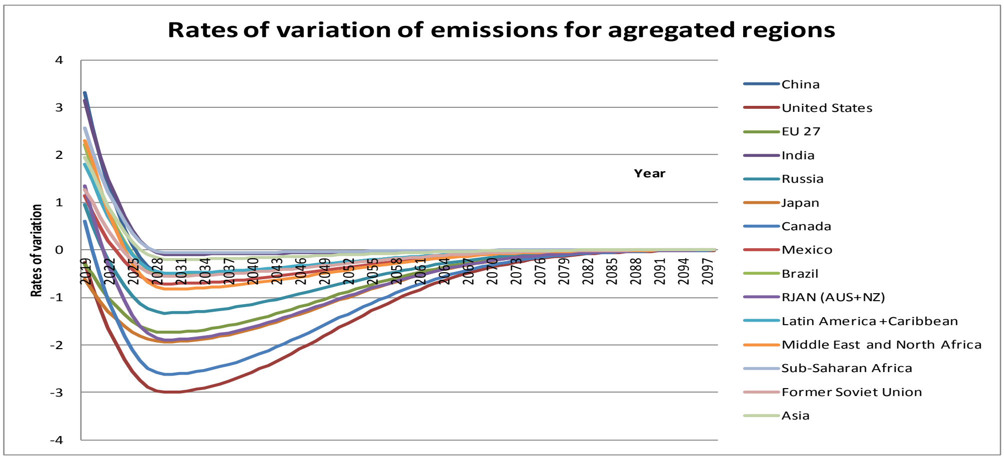
In this scenario, some countries (mostly developing ones) enter the scheme by having positive and, to a certain extent, important rates of emissions increase (left of the graphic) but they start reducing their emissions rapidly. The rate of variation of emissions in countries like China, India or Brazil remains positive for a few years beyond 2020, after which the emissions decline. The hardest effort is accomplished during the second half of the decade (2025-2030). Meanwhile we point out the value of the standard deviation (σ'=0,8) which allows countries like China or India to have rates of variation around –3% around the peak moment, while the EU or the United States are between –5 to –6% (Section 3).

4.2. Early action, Middle Probability limiting the warming at 2°C (Bud.$_{1900\text{-}2100}$=3 626 GteqCO2; t_{peak}=2030; σ'=0,8)

The second scenario, "Early action *md*", is characterized by a lower probability to stabilize the temperature increase, which corresponds to a higher carbon budget in 2100 (3626500 MteqCO2). The peak effort remains in 2030 but the intensity (the maximum) of the rate variation is more or less halved. Some countries only need to stabilize their emissions, while most of the others are to engage efforts to decrease their emissions, but at a less than −2% rate per year. Comparatively with those most countries, the rate of variation of the United States and Canada is higher (coming to −3% at the *peak* moment).

Figure 12: Early action with Middle Probability limiting the warming at 2°C.

Rate of variation of emissions between 2020–2100.

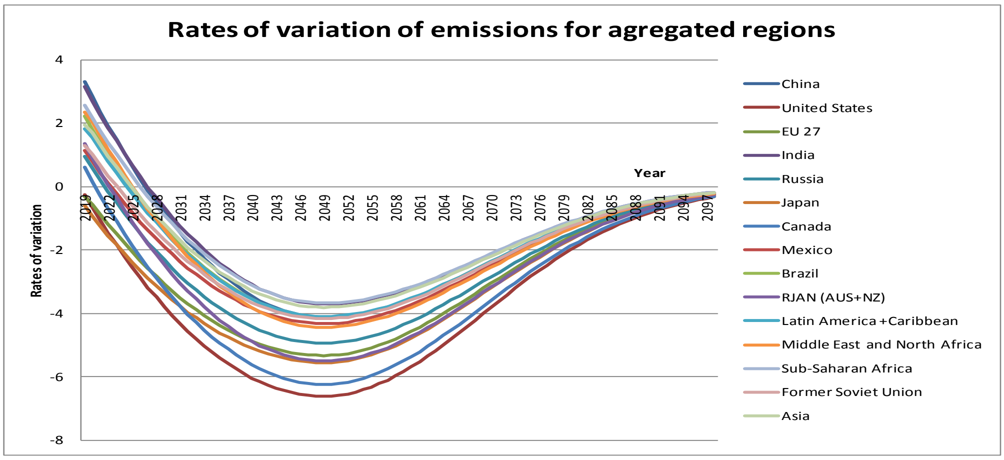


In this case, the decreasing process of the emission rates is less severe. In an early stage, until the peak date, many countries need to slow down their increase of emissions, then stabilize and slightly reduce them afterwards. Generally, only the industrialized countries have to make their efforts exceed the −1% variation rate. On the other hand, as mentioned above, there is an incidence on the carbon budget which will be bigger in the end of period and therefore, there is one in two chances to exceed the 2°C target.

4.3. Delayed Action (Bud.$_{1900\text{-}2100}$=2 302 GteqCO2; t_{peak}=2050; σ'=0,8).

The storyline of the "*Delayed Action"* scenario is quite different. The peak moment is chosen to be in 2050. The yield of the curve is less steep but goes deeper, which indicates that the progression of the efforts, from one year to the other until the peak moment is reduced and, at the same time, the efforts to assume are more important. Thus the *mean* is higher (μ'=4.8), while the efforts are to be maintained for an extensive period of time.

Figure 13: Delayed action. Rate of variation of emissions between 2020 – 2100.

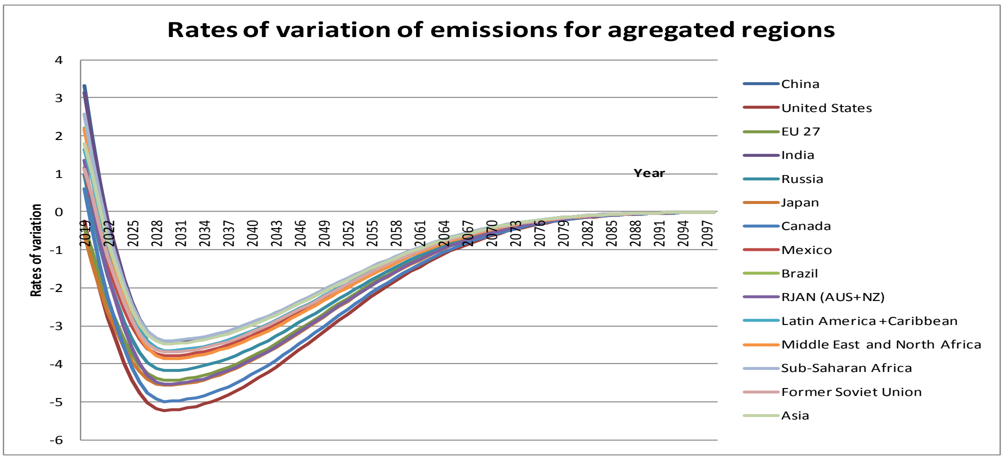


In this scenario most of the countries start their efforts later than in the previous scenario. Generally, for all countries the efforts are brought forth in a more gradual way. For example, China and India should only stabilize their emissions by 2030 and start reducing them afterwards. In exchange, the peak of effort for these two countries is around –4% while for the United States and Canada the peak overruns –6%. Obviously this indicates stronger and longer efforts for all countries in order to achieve the 2°C target. Once again, the rest of the parameters remain unchanged.

4.4. Low differentiation (Bud.=2302000; t_{peak}=2030; σ'=0,5).

The last scenario is the "*Low Differentiation*". The time of the peak is 2030, which indicates that the efforts are to be made rather early, but the standard deviation is smaller than in the previous cases (σ'=0,5). The differentiation of the country profile is concentrated around the mean (*µ')* of –4%. It is not a "one size fits all" type but the countries are less discriminated in their variation rate of emission compared to the previous scenarios.

Figure 14: Low Differentiation. Rate of variation of emissions between 2020 – 2100.



In spite of the low degree of differentiation of the profiles, this scenario still displays significant differences across countries. For example, between India and the United States there is an almost two point difference in their decarbonisation rate, while between Brazil and the EU the difference, while less pronounced, is still of about one point.

5. Relevance of the results and adequacy to the architecture of a future climate regime

The consideration of the above exhibited results requires an analysis of the core elements of the future climate potential agreement process. The starting point of the ADP outcome is to be found in the existing pledges that countries have already put forward for 2020. These commitments have three characteristics:

i. they are fully produced by the countries in a bottom-up process so that they should in principle be put into practice; in other words, there is a certain level of commitment;
ii. they are not ultimate, as it is known that actual commitments are part of the negotiation strategy; so forth, these pledges depend on the commitment of others (we can take for instance the conditional EU pledge); thus, we may assume a certain flexibility;
iii. they are made by an important number of countries, covering over 80% of global GHG emissions in 2010 (except for Turkey, all the AI countries and 57 NAI); one may consider that a critical mass is involved.

Every proposal concerning the architecture of the future climate agreement should start from this evidence, and there is no exception for the Soft Landing approach. Meanwhile, we know that the summing-up of the existing national pledges is projected to lead to a warming of 3.7°C (Hare *et al*. 2013), which is unacceptable in the UNFCCC's terms. In this respect, the results above illustrate a "mechanism" which may facilitate the convergence between the types of commitments that are considered by governments and the warming target of 2°C.

The four scenarios developed in Section 4 indicate different ways in which we may consider the *convergence principle* by using a simple algorithm and in the following we should argue the main points that support this affirmation. All four scenarios, and virtually all scenarios based on the algorithm, exhibit some common features:

- they allow comparability within a comprehensive framework,
- they are based on transparent parameters and principles,
- they ensure smooth emission trajectories and, perhaps most important,
- they are consistent with the carbon budget.

Although the algorithm provides substantial mitigation efforts, the paradigm behind it is not that of "burden sharing" but the providing of references to national "decarbonisation pathways". As mentioned before, countries do already implement different climate policies which lead to emission reductions. These actions can therefore be assimilated with rates of emission variation. The Soft Landing profiles can be used as benchmark for the national emission reduction profiles, allowing countries to assess the difference between the two.

The rate of emission variation or decarbonisation rates, as they are proposed in the REDEM results, are high but they are defined so as to avoid abrupt changes in the rhythm of emission reductions. Considering for example, the *Early Action* scenario, we notice that there is still time for a transition between now and 2020, when the first efforts are to be engaged. Under current assumptions, efforts are already planned but with less intensity. The Early Action scenario shows how to strengthen the policies for the benefit of attaining ambitious global targets.

The *Delayed action* scenario reflects a different way of managing the costs. The efforts are pushed forward in time and the question is to know under what considerations it is worth opting for this scenario type: this might be seen as a choice of a time preference, depending on the chosen discount rate, or as a “second best” solution). In a practical way, all scenarios, provide a long-term vision that allows the anticipation of the necessary actions and instruments to be deployed. The REDEM algorithm enables to consider that countries have to work together in order to achieve the emissions stabilization and that this can be done in different ways, according mostly to two key dimensions of the international climate policy conundrum: the time preference for immediate or delayed action and the degree of differentiation for the national emission trajectories.

6. Conclusion

The current process of climate negotiation is focused on the framing of an outcome supposed to be applicable to all parties to the UNFCCC. Meanwhile, the sum of the mitigation contributions – which are to be based on national circumstances and policies, should be compatible with the 2°C target. In this context the Soft Landing approach provides a rationale to produce mitigation trajectories able to achieve the control of the increase in world temperature. The underlying features of the Soft landing approach are to be found in the transparency aspect – through its easily observable variables and clarity principles, which provide concrete and anticipated effort level.

The REDEM algorithm is designed as a tool for the benchmarking of national emission reduction trajectories. The tool shows a practical way to guide the potential national trajectories, through a convergence mechanism into a comprehensible framework. The algorithm starts from the consideration of a fundamental emission curve shape (peak, plateau and decline) and a consistent way to relate the carbon budget in 2100 to the temperature increase. At the same time, REDEM considers the equity matter, which is provided through the Capacity Responsibility Indicator and afterwards by the use of standard deviation for the differentiation of the national decarbonisation trajectories. The main feature of the algorithm consists in the calculation of the profile of the decarbonisation rate for each individual country while it also fully takes into account the emission profiles and total emission budgets for the all period.

The simulation examples show different ways in which we might conceive the shapes of the emissions’ rate of variation. These elements illustrate the countries’ options and their potential application through a constructive and effective way. The logic of providing national decarbonisation corridors, through different stringency efforts, is based on the idea of a better alignment of national contributions towards the 2°C target. Thus the use of REDEM or its results is to be assessed in the perspective of providing a benchmarking system for national decarbonisation policies.

Acronyms:

AI–Annex I countries

NAI–Non Annex I countries

CBDR–Common but Differentiated Responsibility

PM–Prime Minister

ADP–Ad Hoc Working Group on the Durban Platform for Enhanced Action

AWG-LCA–Ad Hoc Working Group for Long term Cooperative Action

AWG-KP– Ad Hoc Working Group on Further Commitments for Annex I Parties under the Kyoto Protocol

COP–Conference of Parties

REDEM– Reduction of Emissions software

CRI–Capacity Responsibility Indicator

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