38/2009

Raport Badawczy

Research Report

RB/34/2009

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Warszawa 2009

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COMPARISON OF PREPARATORY SIGNAL ANALYSIS TECHNIQUES FOR CONSIDERATION IN THE (POST-)KYOTO POLICY PROCESS

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Praca zgłoszona do druku w *Climatic Change*, poprawiona po recenzjach.
*Badania autora finansowane z projektu własnego MNiSW nr N N519 316735

Warszawa 2009

Comparison of Preparatory Signal Analysis Techniques for Consideration in the (Post-) Kyoto Policy Process

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Key words: Kyoto Protocol, greenhouse gas emissions, emission limitation and reduction commitments, compliance, uncertainty in emission estimates, emissions change-versus-uncertainty analysis, confidence in and detectability of commitments

Abstract

Our study is a preparatory exercise. We focus on the analysis of uncertainty in greenhouse gas emission inventories. Inventory uncertainty is monitored, but not regulated, under the Kyoto Protocol to the United Nations Framework Convention on Climate Change. Under the Convention, countries publish annual or periodic national inventories of greenhouse gas emissions and removals. Policymakers use these inventories to develop strategies and policies for emission reductions and to track the progress of these policies. However, greenhouse gas inventories contain uncertainty for a variety of reasons, and these uncertainties have important scientific and policy implications. For most countries under the Protocol the agreed emission changes are of the same order of magnitude as the uncertainty that underlies their combined (carbon dioxide equivalent) emissions estimates. Here we apply and compare six available techniques to analyze the uncertainty in the emission changes that countries agreed to realize by the end of the Protocol´s first commitment period 2008–2012. Any such technique, if implemented, could `make or break` claims of compliance, especially in cases where countries claim fulfillment of their commitments to reduce or limit emissions. The techniques all perform differently and can thus have a different impact on the design and execution of emission control policies. A thorough comparison of the techniques has not yet been made but is needed when expanding the discussion on how to go about dealing with uncertainty under the Kyoto Protocol and its successer.

1. Introduction

The focus of our study is on the analysis of uncertainty in greenhouse gas (GHG) emission inventories. Inventory uncertainty is monitored, but not regulated, under the Kyoto Protocol (KP) to the United Nations Framework Convention on Climate Change (FCCC, 1992). Under the Convention, countries publish annual or periodic national inventories of GHG emissions and removals, encompassing carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6) (FCCC, 1998: Annex A). Policymakers use these inventories to develop strategies and policies for emission reductions and to track the progress of these policies.

However, GHG inventories (whether at the global, national, corporate, or other level) contain uncertainty for a variety of reasons – for example, the lack of availability of sufficient and appropriate data and the techniques to process them. Uncertainty has important scientific and policy implications. Until recently, relatively little attention has been devoted to how uncertainty in emissions estimates is dealt with and how it might be reduced. Now this situation is changing, with uncertainty analysis increasingly being recognized as an important tool for improving inventories of GHG emissions and removals (e.g., IPIECA, 2007; Lieberman *et al.*, 2007).

At present, Parties to the UNFCCC are encouraged, but not obliged, to include with their periodic reports of in-country GHG emissions and removals, estimates of the uncertainty associated with these emissions and removals; consistent with the Intergovernmental Panel on Climate Change's (IPCC) good practice guidance reports (Penman *et al.*, 2000, 2003). Yet, it makes a big difference in the framing of policies whether or not uncertainty is considered: reactively, because there is a need to do so; or proactively, because difficulties are anticipated.

Our tenet is that uncertainty estimates are not intended to dispute the validity of national GHG inventories. Although the uncertainty of emissions estimates underscores the lack of accuracy that characterizes many source and sink categories, its consideration can help to establish a more robust foundation on which to base policy. According to the IPCC good practice guidance reports (notably, Penman *et al.*, 2000: p. 6.5), uncertainty analysis is intended to help "improve the accuracy of inventories in the future and guide decisions on methodological choice". Uncertainty analyses function as indicators of opportunities for improvement in data measurement, data collection, and calculation methodology. Only by identifying elements of high uncertainty can methodological changes be introduced to address them. Currently, most countries that perform uncertainty analyses do so for the express purpose of improving their future estimates; and the rationale is generally the same at the corporate and other levels. Estimating uncertainty helps to prioritize resources and to take precautions against undesirable consequences.

Our rationale for performing uncertainty analysis is to provide a policy tool, a means to adjust inventories or analyze and compare emission changes in order to determine compliance or the value of a transaction. The aim of our study is to provide a preparatory guide for dealing with uncertainty in the (post-) Kyoto policy process. We apply and compare six available techniques to analyze uncertain emission changes (also called emission signals) that countries agreed to realize by the end of the Protocol's first commitment period 2008–2012. A thorough comparison of the techniques has not yet been made available. Even more unsatisfying, although highly needed, techniques to analyze uncertain emission signals from various points of view, ranging from signal quality (defined adjustments, statistical significance, detectability, etc.) to the way uncertainty is addressed (trend uncertainty or total uncertainty) are not in place. For most countries under the Protocol (Annex B countries) the agreed emission changes are of the same order of magnitude as the uncertainty that underlies their combined (carbon dioxide equivalent) emissions estimates (Table 1: compare last column on the left with first column on the right). Any such technique, if implemented, could 'make or break' claims of compliance, especially in cases where countries claim fulfillment of their commitments to reduce or limit emissions.

Table 1

Moreover, as demonstrated by Jonas *et al.* (2004b, c), Bun and Jonas (2006), Hamal and Jonas (2008a, b) and Bun *et al.* (this issue), these techniques could also be used to serve monitoring purposes. Emission changes since 1990 (base year of most Annex B countries) that are reported annually can be evaluated in an emissions change-versus-uncertainty context rather than an emissions change-only context. This advanced monitoring service is also not provided under the Protocol.[1]

Jonas *et al.* (2004a) distinguish between preparatory signal analysis, midway signal analysis, and signal analysis in retrospect (see also http://www.iiasa.ac.at/Research/FOR/unc_changes.html). Preparatory signal analysis is most advanced. It allows generating useful information beforehand as to how great uncertainties can be depending on the level of confidence of the emission signal, or the signal one wishes to detect, and the risk one is willing to tolerate in not meeting an agreed emission limitation or reduction commitment. We are aware of at least six different preparatory signal analysis techniques, some of which have been presented at the 1st International Workshop on Uncertainty in GHG Inventories (Gillenwater *et al.*, 2007; Jonas and Nilsson, 2007; Nahorski *et al.*, 2007). These techniques need to be scrutinized further, now in a comparative mode, before a discussion on which of them to select can take place. They all agree that uncertainty analysis is a key component of GHG emission analysis. However, the techniques all perform differently and thus can have a different impact on the design and execution of emission control policies. Going through this comparative exercise and making this knowledge available is a legacy of the 1st International Workshop on Uncertainty in GHG Inventories held 2004 in Warsaw, Poland. This exercise is required prior to advancing the discussion on how to go about dealing with uncertainty under the KP and its successor.

This comparison is technical by nature, which is why we impart non-technical introductions and explanations to each section. We provide an overview of the techniques and their characteristics, and the conditions under which they are applied and compared in **Section 2**. In **Section 3** we describe each technique in a standardized fashion. We make available mathematical details to and numerical results for all techniques as supporting online material (SOM) at http://www.iiasa.ac.at/Research/FOR/unc_prep.html.[2] We summarize our findings in **Section 4**.

2. Overview of Techniques and Their Characteristics and Conditions of Application

In the following section we apply and compare six techniques to analyze the uncertainty in the emission changes that countries agreed to realize by the end of the Protocol's first commitment period 2008–2012. **Table 2** summarizes the spatio-temporal and thematic conditions under which the application and comparison are carried out. The conditions are shaped by the KP and imply the country scale and the countries' annual emissions of the six GHGs as listed in Appendix A and B to the Protocol (FCCC, 1998). Box 1 recapitulates the relevant uncertainty terms and concepts that we refer to and make use of in our study.

Table 2

Box 1

Table 3

Table 3 lists the six signal analysis techniques and summarizes their major characteristics which are explained in detail in Section 3. These are (1) the critical relative uncertainty (CRU) concept; (2) the verification time (VT) concept; (3) the undershooting (Und) concept; (4) the undershooting and VT (Und&VT) concepts combined; (5) the adjustment of emissions (Gillenwater, Sussman and Cohen—GSC #1) concept; and (6) the adjustment of emission reductions (Gillenwater, Sussman and Cohen—GSC #2) concept.

To ensure that all techniques can be compared to each other, they refer to GHG emissions at two points in time, base year and commitment year, of each country group (see Tables 1, 2), and are operated under relative emission limitation or reduction (commitment) conditions with uncertainty expressed in relative terms. Relative uncertainty can range widely depending on the system of GHGs studied (see Box 1 and right sight of Table 1).

The major difference between the techniques is whether they follow the concept of trend or total uncertainty (see first and second row in Table 3 and Box 1 for explanations). This determines whether we classify a technique capable of pursuing an "intra-systems view" or even an "intra-systems view that is suited to support an inter-systems (top-down) view" (see third and fourth row in **Table 3**). The KP can be used as a good example for explaining the difference. The Protocol splits the terrestrial biosphere into directly human-impacted (managed) and not directly human-impacted (natural) parts. However, this artificial separation makes it impossible to estimate the reliability of any system output if only part of the system is considered. The tacit assumptions underlying this approach are that man's impact on nature, the not-accounted remainder under the Protocol, is irrelevant and inventory uncertainty only matters from a relative point of view over space and time, not an absolute one. But such an approach is highly problematic because biases (i.e., discrepancies between true and reported emissions), typically resulting from partial accounting, are not uniform across space and time. In addition, man's impact on nature need not be constant or negligible.[4]

3. Preparatory Signal Analysis Techniques

This section is technical by nature. It compares the six preparatory signal analysis techniques listed in **Table 3**. They allow analyzing the emission changes that countries agreed to realize by the end of the Protocol's first commitment period 2008–2012 in an uncertainty context with uncertainty expressed in relative terms and taking on the median values of the intervals specified in **Box 1**. Each technique is described by following a standard template which addresses: the technique's starting point for its application; the assumptions made; the systems view followed; the main question(s) addressed; the approach taken; the answer expressed in mathematical terms; and the numerical results; followed by a verbal description of the technique's mathematical-numerical behavior. For both the more detailed mathematical background (SOM_Math) and the more complete set of numerical results (SOM_Num) the reader is referred to the supporting online material.[2]

3.1 CRU Concept

The CRU concept is the easiest of the techniques and most straightforward. It centers on the commitment year and asks the question what the maximal (or critical) relative uncertainty is that a country can report to ensure favorable detection at that point in time. Here and in the remainder of the study 'detection' means that the absolute change in net emissions outstrips absolute uncertainty in the commitment year.

Starting Point: Annex B countries comply with their emission limitation or reduction commitments under the KP.

Assumptions: (1) The relative uncertainty (ρ) of a country's net emissions (x) shall be symmetrical and not change over time, i.e., $\rho_1 = \rho_2 (:= \rho)$.[5]

(2) The absolute change in net emissions shall outstrip absolute uncertainty (ε) at t_2, i.e., $|x_1 - x_2| > \varepsilon_2$.

Systems View: Intra-systems view suited to support inter-systems (top-down) view: Only our real diagnostic capabilities of grasping emissions at any point in time individually—reflected by absolute uncertainty $\varepsilon(t)$ —are of interest. Correlation of uncertainty over time does not matter.

Question: What are the critical relative uncertainties (CRUs) that can be reported by Annex B countries to ensure favorable detection in the commitment year?

Approach: Deterministic (see Figure 1).

Figure 1

Answer: The answer is given by Eq. A-6 in SOM_Math: Appendix A

$$\rho_{\text{crit}} := \frac{|\delta_{\text{KP}}|}{(1-\delta_{\text{KP}})}, \tag{A-6}$$

where ρ_{crit} is the CRU; and δ_{KP} the normalized emissions change committed under the KP between t_1 and t_2 ($\delta_{\text{KP}} > 0$: emission reduction; $\delta_{\text{KP}} \leq 0$: emission limitation).

Result: The numerical result is given by Table 4 (see also Table A-1 in SOM_Math and worksheet *Crit Rel Unc 1* in SOM_Num).

Table 4

Table 4 lists δ_{KP} and ρ_{crit} for all Annex B countries under the KP. A country of group 1, e.g., has committed itself to reduce its net emissions by 8% (2nd column). In the case of compliance and under the condition of constant relative uncertainty, the country's net emissions in the commitment year (t_2) only satisfy this concept favorably if they are estimated with a relative uncertainty smaller than 8.7% (3rd column). With reference to the total uncertainty estimates that are reported annually by the EU Member States for all Kyoto gases (most recently: EEA, 2009), it must be expected that these countries exhibit in the commitment year relative uncertainties in the range of 5–10% and above rather than below (excluding land use, land-use change, and forestry (LULUCF) and Kyoto mechanisms). Thus, achieving a relative uncertainty smaller than 8.7% appears difficult for quite a few, especially data poor, Annex B countries.

The CRU concept exhibits a dissimilarity between emission limitation ($\delta_{\text{KP}} < 0$) and reduction ($\delta_{\text{KP}} > 0$). This can be immediately seen when comparing the CRUs that belong to δ_{KP} values that are equal in absolute terms (see, e.g., country groups 1 and 7: ± 8.0%). This has consequences when defining stricter or more lenient Kyoto emission targets. For instance, in the case of increasingly stricter Kyoto emission targets (let $\delta_{\text{KP}} < 0$ increase), Annex B countries committed to emission limitation must decrease their uncertainties according to this concept; their CRUs decrease. In contrast, countries committed to emission reduction do not need to do so (let $\delta_{\text{KP}} > 0$ increase); their uncertainties can even increase because their CRUs also increase and can be met more easily. The opposite is true in the case of increasingly more lenient Kyoto emission targets. Annex B countries committed to emission reduction must decrease their uncertainties in order to satisfy decreasing CRUs (let $\delta_{\text{KP}} > 0$ decrease), while countries committed to emission limitation can even increase their uncertainties because their CRUs also increase and can be met more easily (let $\delta_{\text{KP}} < 0$ decrease).

According to this concept the stabilized emissions case ($\delta_{\text{KP}} = 0$) should not be allowed—it presupposes zero uncertainty—unless it is ascertained beforehand that relative uncertainties are, or can be expected to be, at least small.

3.2 VT Concept

The VT concept goes beyond the CRU concept. In its most simplified version (as employed here) it takes the linear dynamics of the emission signal between base year and commitment year into account and can thus be used to qualify in relative terms the degree of detectability achieved in the commitment year.

Starting Point: Annex B countries comply with their emission limitation or reduction commitments under the KP.

Assumptions: (1) The relative uncertainty (ρ) of a country's net emissions (x) shall be symmetrical and not change over time, i.e., $\rho_1 = \rho_2\,(:= \rho)$.

(2) The absolute change in net emissions shall outstrip absolute uncertainty at time t (which can be $\leq$ or $> t_2$), i.e., $\left|\Delta x(t)\right| > \varepsilon(t)$.

Systems View: Intra-systems view suited to support inter-systems (top-down) view: Only our real diagnostic capabilities of grasping emissions at any point in time individually—reflected by absolute uncertainty $\varepsilon(t)$ —are of interest. Correlation of uncertainty over time does not matter.

Question: What are the times (also called verification times; VTs) when the countries' emission signals outstrip uncertainty?[7]

Approach: Deterministic (see Figure 2).

Figure 2

Answer: The answer is given by Ineq. B-7a in SOM_Math: Appendix B

$$\frac{\Delta t}{t_2 - t_1} > \frac{\rho}{|\delta_{KP}| + \delta_{KP}\rho} , \tag{B-7a}$$

where Δt is the VT; and $t_2 - t_1$ the time between base year and commitment year/period upon which the VT is normalized.

Result: The numerical result is given by Table 5 (see also Table B-1 in SOM_Math and worksheet *Verification Time 1* in SOM_Num).

Table 5

Table 5 lists normalized VTs for all Annex B countries under the KP. The VT concept provides a more detailed detection perspective for negotiators of the Protocol than the CRU concept presented in Section 3.1. It quantifies in detail what the consequences are in the form of normalized VTs if countries report emissions with relative uncertainties that are ≤ or > ρ_{crit}. Here we explore the range from 2.5 to 30% relative uncertainty, which is given by the medians of classes 1 and 4 (see Box 1 and right side of Table 1).

Moreover, the VT concept corroborates the dissimilarity between emission limitation and reduction, which has already been found for the CRU concept and which is a direct consequence of not demanding a uniform δ_{KP} for all countries under the Protocol. While both the VT concept and the CRU concept favor stricter over more lenient Kyoto emission targets in the case of emission reduction ($\delta_{KP} > 0$), this is not so in the case of emission limitation ($\delta_{KP} < 0$) where the two concepts favor more lenient over stricter

Kyoto emission targets (because compliance with normalized VTs < 1 becomes less difficult in either case). This is not in line with the spirit of the KP.

3.3 Und Concept

Inventoried emissions of GHGs are uncertain, and this uncertainty translates into a risk that true emissions are greater than those estimated and reported. Undershooting helps to limit, or even reduce, this risk – which is what the Und concept allows doing. In contrast to both the CRU concept and the VT concept, the Und concept also accounts for the uncertainty in the emissions estimates in the base year when assessing compliance with the countries' commitments in the commitment year.

The Und concept follows the footsteps of statistical significance in quantifying the aforementioned risk. It correlates uncertainty between base year and commitment year and also allows factoring in a change in uncertainty, which can be due to learning and or result from structural changes in the emitters. However, here we assume that our knowledge of uncertainty stays constant over time in relative terms (first-order approach). This is because researchers are only beginning to diagnose estimated changes in the uncertainty of GHG emissions (notably, CO_2 emissions from fossil fuel burning, Hamal, 2010) and separate their causes.

Starting Point: Annex B countries comply with their emission limitation or reduction commitments under the KP.

Assumptions: (1) Uncertainties at t_1 and t_2 are given in the form of intervals, which take into account that a difference (ε) might exist between the true (t) but unknown net emissions (x_t) and their best estimates (x).

(2) The relative uncertainty (ρ) of a country's net emissions is symmetrical and does not change over time, i.e., $\rho_1 = \rho_2 \left(:= \rho\right)$.

Systems View: Intra-systems view: Correlation of uncertainty over time matters.

Question: Taking into account the combined uncertainty at t_2 and considering that the true emissions are not known, how much undershooting (Und) is required to limit the risk α that countries overshoot their true emission limitation or reduction commitments?

Approach: Quasi-statistical, based on interval calculus (see Figure 3).

Figure 3

Answer: The answer is given by Eq. C-13 in combination with Eq. C-15 and Eq. C-18 in SOM_Math: Appendix C

$x_{t,2} \geq \left(1-\delta_{KP}\right)x_{t,1}$ with risk α $\Leftrightarrow$

$$\frac{x_2}{x_1} \leq \left(1-\delta_{KP}\right)\frac{1-\left(1-2\alpha\right)\left(1-\nu\right)\rho}{1+\left(1-2\alpha\right)\left(1-\nu\right)\rho} = 1-\delta_{mod}, \qquad \text{(C-13a,c)}$$

where v approximates (first-order approach) the net (effective) correlation between ε_1 and ε_2; and δ_{mod} is the countries' modified (mod) emission limitation or reduction targets defined by

$$\delta_{mod} = \delta_{KP} + U \tag{C-15}$$

and U the undershooting given by

$$U = 2(1-\delta_{KP})\frac{(1-2\alpha)(1-\nu)\rho}{1+(1-2\alpha)(1-\nu)\rho} \; . \tag{C-18}$$

Result: The numerical result is given by Table 6 (see also Table C-1 in SOM_Math and worksheet *Undershooting 4a* in SOM_Num).

Table 6

Table 6 lists δ_{mod} values as a result of applying Eq. C-15 in combination with Eq. C-18. δ_{KP}, ρ and α are treated as parameters, while the correlation v is 0.75 (typical for currently reported uncertainties; most recently: EEA 2009: Table 1.20).[8] Table 6 shows that the Und concept is difficult to justify politically in the context of the KP. Under the Protocol, nonuniform emission limitation or reduction commitments (see δ_{KP} values in the second column) were determined 'off the cuff', meaning that they were derived via horse-trading and not resulting from rigorous scientific considerations. The outcome is discouraging. Varying δ_{KP} while keeping the relative uncertainty ρ and the risk α constant exhibits that Annex B countries that must comply with a smaller δ_{KP} (they exhibit a small δ_{mod}) are better off than countries that must comply with a greater δ_{KP}

(they exhibit a great δ_{mod}). (See, e.g., δ_{mod} values in red for $\rho = 7.5\%$ and $\alpha = 0.3$.) The choice of δ_{KP} dominates Eq. C-15, while the influence of δ_{KP} on U (see Eq. C-18: U↑ for δ_{KP}↓ and vice versa) is negligible and does not compensate for agreed deviations in the δ_{KP} values. Such a situation is not in line with the spirit of the KP.

This situation would be different if the nonuniformity of the emission limitation or reduction commitments were the outcome of a rigorously based process resulting in a straightforward rule that applies equally to all countries, as it would be the case, for instance, under the widely discussed contraction and convergence (C&C) approach; e.g., WBGU, 2003: Section 2.3; Pearce, 2003). Under such conditions, it would be the undershooting U that matters, not the modified emission limitation or reduction target δ_{mod}.

3.4 Und&VT Concepts Combined

The Und&VT concept seeks to combine the strengths of both the introduction of risk by the Und concept and the explicit consideration of time by the VT concept in detecting an emission signal. That is, the Und&VT concept also allows undershooting to limit, or even reduce, the risk that true emissions are greater than those estimated and reported; and it addresses the degree of detectability achieved in the commitment year. The Und&VT concept accounts, like the VT concept, for the linear dynamics of the emission signal between base year and commitment year, and uncertainty at the latter. In contrast to the Und concept, it thus follows the footsteps of signal detection in quantifying the aforementioned risk. Concomitantly, the Und&VT seeks to overcome some of the undesirable properties of both the VT concept (countries committed to equal emission limitation and reduction targets in absolute terms are treated dissimilar) and the Und concept (countries committed to different emission changes under the KP are assigned different modified emission limitation or reduction targets)

Starting Point: Annex B countries comply with their emission limitation or reduction commitments under the KP.

Assumptions: (1) Uncertainties at t_1 and t_2 are given in the form of intervals, which take into account that a difference (ε) might exist between the true (t) but unknown net emissions (x_t) and their best estimates (x).

(2) The relative uncertainty (ρ) of a country's net emissions is symmetrical and does not change over time, i.e., $\rho_1 = \rho_2 (:= \rho)$.[9]

(3) The absolute change in net emissions shall outstrip uncertainty at time $t \leq t_2$, i.e., the VT shall be equal to, or smaller than, the maximal allowable VT ($\Delta t \leq t_2 - t_1$).

Systems View: Intra-systems view suited to support inter-systems (top-down) view: Only our real diagnostic capabilities of grasping emissions at any point in time individually—reflected by absolute uncertainty $\varepsilon(t)$ —are of interest. Correlation of uncertainty over time does not matter.

Question: Referring to risk as the strength of the Und concept and to time in detecting an emission signal as the strength of the VT concept, can these concepts be combined (Und&VT) to take advantage of the two?

Approach: Quasi-statistical, based on interval calculus (see Figure 4).

Figure 4

Answer: The answer comprises four cases depending on how δ_{crit}, the critical emission limitation or reduction, and δ_{KP} relate to each other (see Figure 4). δ_{crit} allows distinguishing between detectable and nondetectable emission changes.[10] The complete answer is given by (see SOM_Math: Appendix D for the equations mentioned below)

Case 1: $\delta_{KP} > 0$: $\delta_{crit} \leq \delta_{KP}$:

$x_{t,2} \geq (1-\delta_{KP})x_{t,1}$ with risk α $\Leftrightarrow$

$$\frac{x_2}{x_1} \leq (1-\delta_{KP})\frac{1}{1+(1-2\alpha)\rho} = 1-\delta_{mod}\ , \qquad \text{(D-3), (C-13c)}$$

where δ_{mod} is defined as before (see Eq. C-15) and U is given by

$$U = (1-\delta_{KP})\frac{(1-2\alpha)\rho}{1+(1-2\alpha)\rho}\ . \qquad \text{(D-5)}$$

Case 2: $\delta_{KP} > 0$: $\delta_{crit} > \delta_{KP}$:

$x_{t,2} \geq (1-\delta_{crit})x_{t,1}$ with risk α $\Leftrightarrow$

$$\frac{x_2}{x_1} \leq \left(1-\delta_{\text{crit}}\right)\frac{1}{1+\left(1-2\alpha\right)\rho} = 1-\delta_{\text{mod}} \ , \qquad \text{(D-6), (C-13c)}$$

where δ_{mod} is defined as before (see Eq. C-15) and U is given by

$$U = U_{\text{Gap}} + \left(1-\delta_{\text{crit}}\right)\frac{\left(1-2\alpha\right)\rho}{1+\left(1-2\alpha\right)\rho} \qquad \text{(D-8)}$$

with

$$U_{\text{Gap}} = \delta_{\text{crit}} - \delta_{\text{KP}} \ . \qquad \text{(D-9)}$$

Case 3: $\delta_{KP} \leq 0$: $\delta_{crit} < \delta_{KP}$:

$x_{t,2} \geq \left(1+\delta_{\text{crit}}\right)x_{t,1}$ with risk α ⇔

$$\frac{x_2}{x_1} \leq \left(1+\delta_{\text{crit}}\right)\frac{1}{1+\left(1-2\alpha\right)\rho} = 1-\delta_{\text{mod}} \ , \qquad \text{(D-10), (C-13c)}$$

where δ_{mod} is defined as before (see Eq. C-15) and U is given by

$$U = U_{\text{Gap}} + \left(1+\delta_{\text{crit}}\right)\frac{\left(1-2\alpha\right)\rho}{1+\left(1-2\alpha\right)\rho} \qquad \text{(D-12)}$$

with

$$U_{\text{Gap}} = -\left(\delta_{\text{KP}} + \delta_{\text{crit}}\right) \ . \qquad \text{(D-13)}$$

Case 4: $\delta_{KP} \leq 0$: $\delta_{crit} \geq \delta_{KP}$:

$x_{1,2} \geq \left(1+\delta'_{\text{crit}}\right)x_{1,1}$ with risk α ⇔

$$\frac{x_2}{x_1} \le \left(1+\delta'_{\text{crit}}\right)\frac{1}{1+\left(1-2\alpha\right)\rho} = 1-\delta_{\text{mod}} \ , \qquad \text{(D-14), (C-13c)}$$

where δ_{mod} is defined as before (see Eq. C-15) and U is given by

$$U = U_{\text{Gap}} + \left(1+\delta'_{\text{crit}}\right)\frac{\left(1-2\alpha\right)\rho}{1+\left(1-2\alpha\right)\rho} \qquad \text{(D-16)}$$

with

$$U_{\text{Gap}} = -2\delta_{\text{crit}} \qquad \text{(D-17)}$$

$$-\delta'_{\text{crit}} = \delta_{\text{KP}} - 2\delta_{\text{crit}} \ . \qquad \text{(D-18)}$$

U_{Gap} in Cases 2–4 is an initial obligatory undershooting, which is introduced to ensure that detectability is achieved before Annex B countries are permitted to make economic use of potential excess emission reductions.

Result: The numerical is given by Table 7 (see also Table D-3 in SOM_Math and worksheet *Und&VT 2a* in SOM_Num).

Table 7

Table 7 lists δ_{mod} values as a result of applying Eq. C-15 in combination with: Eq. D-5 (Case 1), Eq. D-8 to D-9 (Case 2), Eq. D-12 to D-13 (Case 3), and Eq. D-16 to D-18 (Case 4). δ_{KP}, ρ and α are treated as parameters. By employing δ_{crit} as a uniform detectability criterion, the Und&VT concept overcomes the dissimilarity of both the VT concept and the CRU concept between countries committed to emission reduction

($\delta_{KP} > 0$) and emission limitation ($\delta_{KP} \leq 0$), which arises if more lenient or stricter Kyoto emission targets are introduced (cf. with Tables 4 and 5). Moreover, the Und&VT concept also rectifies Cases 2 and 3, the cases of nondetectability (before correction), that is, the politically unfavourable situation under the Und concept under which countries complying with a small δ_{KP} exhibit a small δ_{mod}, while countries complying with a great δ_{KP} exhibit a great δ_{mod} (cf. with Table 6).

However, this concept reveals a crucial difficulty from a political perspective. The Und&VT concept requires the Protocol's Kyoto emission targets to be corrected through the introduction of an initial obligatory undershooting (U_{Gap}) so that the countries' emission reductions, not limitations, become detectable (i.e., meet the maximal allowable VT) before the countries are permitted to make economic use of their excess emission reductions. (See, e.g., group 1 countries in Table 7 ($\delta_{KP} = 8\%$) under Case 2 conditions: the δ_{mod} value for $\rho = 15\%$ and $\alpha = 0.5$ is $\delta_{mod} = \delta_{KP} + U_{Gap} = 13\%$ ($U = U_{Gap}$); that is, the initial obligatory undershooting is $U_{Gap} = 13\% - 8\% = 5\%$.) It remains to be seen whether this strict interpretation of signal detection will be accepted by Annex B countries as it forces them to strive for detectability, i.e., to make initial investments before they can profit from their economic actions. Notwithstanding, opponents to this concept must realize that the countries' detectability, i.e.: the ' $x_{t,2}$ -greater-than-$(1-\delta_{KP})x_{t,1}$' risk (Case 1), the '$x_{t,2}$-greater-than-$(1-\delta_{crit})x_{t,1}$' risk (Case 2), the '$x_{t,2}$-greater-than-$(1+\delta_{crit})x_{t,1}$' risk (Case 3), and the '$x_{t,2}$-greater-than-$(1-(\delta_{KP}-2\delta_{crit}))x_{t,1}$'

risk (Case 4) of their emission signals can be grasped – and thus be priced – although the countries' true net emissions at t_1 and t_2 are unknown!

3.5 GSC #1 Concept

GSC #1 refers to the first of the two concepts that Gillenwater *et al.* presented in 2007, following the notion of adjusting the countries' national emissions in response, and according, to the estimated uncertainties and a statistically valid method. The GSC #1 concept centers on the commitment year and requires confidence that, when countries report emissions inventories that nominally are in agreement with their commitments under the Protocol, the countries truly are, if not in compliance, at least within a given tolerance of complying with their commitments. That is, the GSC #1 concept considers a relative upward adjustment that seeks to attain a reasonable level of confidence that countries have actually achieved their target emissions stated in their commitments under the KP and are in compliance. Ultimately, countries must reduce their emissions in the commitment year by the amount of their upward adjustment to remain in compliance.

Starting Point: Annex B countries comply with their emission limitation or reduction commitments under the KP.[11]

Assumptions: (1) It is accepted *a priori* that the true, but unknown, net emissions at t_2 ($x_{t,2}$) can exceed (overshoot) the target emissions commitment (x_2) by some fractional or percentage amount (p or p%, respectively).

(2) The relative uncertainty (ρ) of a country's net emissions is symmetrical and does not change over time, i.e., $\rho_1 = \rho_2 (:= \rho)$.[12]

(3) The probability distributions for estimated emissions are normal and the shape of the emissions probability distribution for each country does not change significantly as emissions change.

Systems View: Intra-systems view suited to support inter-systems (top-down) view: Only our real diagnostic capabilities of grasping emissions at any point in time individually—reflected by absolute uncertainty $\varepsilon(t)$ —are of interest. Correlation of uncertainty over time does not matter.

Question: Can we attain a reasonable level of confidence that countries will have actually achieved the target emissions levels stated in their commitments under the KP and are in compliance? That is: 1) Would we consider it acceptable if true emissions will exceed (overshoot) the target emissions commitment by some fractional or percentage amount? 2) How much is that amount? 3) How confident do we want to be in our result?

Approach: Statistical (see Figure 5).

Figure 5

Answer: Depending on whether or not excess emissions are accepted and favorable compliance conditions exist *a priori*, the modified GSC #1 concept of Gillenwater *et al.* comprises three cases (see Figure 5). The complete answer is given by (see SOM_Math: Appendix E for the equations mentioned below)

Cases 1 and 2: $\delta_{KP} > 0$: $p = \delta_{crit}$:

$$\mathrm{Adj} = \begin{cases} 1 & \text{for} \quad 1 + z_{u,2}\left(F_N\right)\dfrac{\rho}{1.96} \le 1 + \rho_{crit} \\ & \qquad \text{(excess emissions accepted)} \\ \dfrac{1 + z_{u,2}\left(F_N\right)\dfrac{\rho}{1.96}}{1 + \rho_{crit}} & \qquad 1 + z_{u,2}\left(F_N\right)\dfrac{\rho}{1.96} > 1 + \rho_{crit} \\ & \qquad \text{(excess emissions accepted)} \end{cases} \qquad \text{(E-7,8)}$$

Case 3: $\delta_{KP} \le 0$: $p = 0$:

$$\mathrm{Adj} = 1 + z_{u,2}\left(F_N\right)\frac{\rho}{1.96} \qquad \text{(excess emissions not accepted),} \qquad \text{(E-9)}$$

where p specifies the accepted (fractional) amount by which true emissions can exceed target emissions commitments; $\rho/1.96$ is the standard deviation; F_N the standardized cumulative normal distribution; $z_{u,2}$ the standardized accepted upper (u) emissions limit at t_2; ρ_{crit} the CRU introduced in Section 3.1; and Adj the resulting upward adjustment of the country's emissions estimate relative to its KT (i.e., *de facto* an emissions reduction by this amount more than the country's commitment to remain in compliance).

Result: The numerical result is given by Table 8 (see also Table E-1 in SOM_Math and worksheet *GSC_1 1a* in SOM_Num).

Table 8

Table 8 lists adjustment (Adj) values as a result of applying Eq. E-7 (Case 1), Eq. E-8 (Case 2) and Eq. E-9 (Case 3). They specify the required upward adjustment of the country's emissions estimate or, equivalently, the *de facto* emissions reduction by this amount more than the country's commitment to remain in compliance with commitments. For any given δ_{KP} value (thus, ρ_{crit} value; see Eq. A-6 in Section 3.1), inventory uncertainty (ρ) is treated as parameter as well as the confidence $(1-\alpha)$ that true emissions do not exceed (overshoot) target emissions by more than $p=\delta_{crit}$ (Cases 1 and 2: this value for p ensures that, relative to committed target emissions, base year emissions are not exceeded) and $p=0$ (Case 3: excess emissions are not accepted in the case of emission limitation). The confidence $(1-\alpha)$ is specified to be 0.9, 0.7 and 0.5. The table shows that the GSC #1 concept is not easy to handle because it requires strict enforcement under the KP. Emission reduction $(\delta_{KP}>0)$ under the GSC #1 concept behaves mirror-inverted to the Und concept as a consequence of nonuniform emission reduction commitments: Varying δ_{KP} while keeping the relative uncertainty ρ and the confidence $(1-\alpha)$ constant exhibits that Annex B countries that must comply with a great δ_{KP} (they exhibit a small Adj) are better off than countries that must comply with a small δ_{KP} (they exhibit a great Adj). (See, e.g., Adj values in red for $\rho=15\%$ and

$1-\alpha=0.9$.) However, this is only true if adjustments must be compensated for by additional emission reductions (undershooting mode) and are not misused by policy and decision-makers to only establish a country comparison in terms of confidence (confidence mode) not resulting in a compulsory undershooting. In the latter case, countries that must comply with a small δ_{KP} (they exhibit a great Adj) are better off than countries that must comply with a great δ_{KP} (they exhibit a small Adj). This situation would not be in line with the spirit of the KP.

3.6 GSC #2 Concept

GSC #2 refers to the second of the two concepts that Gillenwater *et al.* presented in 2007. In contrast to GSC #1, their second concept accounts also for the uncertainty in the emissions estimates in the base year when assessing compliance with the countries' commitments in the commitment year. The GSC #2 concept requires confidence that, when countries report emissions inventories that nominally are in agreement with their commitments under the Protocol, emissions have actually been reduced by an amount equal to the emissions difference between base-year and commitment year, i.e., estimated emission reductions should not be "off" by more than a certain amount. That is, the GSC #2 concept considers a relative upward adjustment that seeks to attain a reasonable level of confidence that countries have actually achieved the emission reductions, measured relative to base-year emissions, stated in their commitments under the KP and are in compliance. Ultimately, countries must reduce their emissions in the commitment year by the amount of their upward adjustment to remain in compliance.

Starting Point: Annex B countries comply with their emission limitation or reduction commitments under the KP.[11]

Assumptions: (1) It is accepted *a priori* that true emission reductions (increases) fall below (above) the committed level of reductions (increases) by some fractional or percentage amount (p or p%, respectively).

(2) The relative uncertainty (ρ) of a country's net emissions is symmetrical and does not change over time, i.e., $\rho_1 = \rho_2 \left(:= \rho\right)$.

(3) The probability distributions for estimated emissions and emission changes are normal and the shape of the emissions and emissions change probability distributions for each country do not change significantly as emissions change.

Systems View: Intra-systems view: Correlation of uncertainty over time matters.

Question: Can we attain a reasonable level of confidence that countries will have actually achieved the emission changes, measured relative to base-year emissions, stated in their commitments under the KP and are in compliance? That is: 1) Would we consider it acceptable if true emission reductions (increases) will fall below (above) the committed level of reductions (increases) by some fractional or percentage amount? 2) How much is that amount? 3) How confident do we want to be in our result?

Approach: Statistical (see Figure 6).

Figure 6

Answer: Depending on whether or not diminished reductions (additional increases) are accepted and favorable compliance conditions exist *a priori*, the modified GSC #2 concept of Gillenwater *et al.* comprises four cases (see Figure 6). The complete answer is given by (see SOM_Math: Appendix F for the equations mentioned below)

Cases 1 and 2: $\delta_{KP} > 0$: $p = 0.1$:

$$\mathrm{Adj} = \begin{cases} 1 & \text{for } 2(1-\mathrm{v})\dfrac{z_{u,2}(F_N)\rho}{1.96\rho_{\mathrm{crit}}} \le 0.1 \;\; \text{diminished reduction accepted} \\[2ex] \dfrac{1-\left(1-2(1-\mathrm{v})\dfrac{z_{u,2}(F_N)\rho}{1.96\rho_{\mathrm{crit}}}\right)\delta_{KP}}{1-0.9\delta_{KP}} & \text{for } 2(1-\mathrm{v})\dfrac{z_{u,2}(F_N)\rho}{1.96\rho_{\mathrm{crit}}} > 0.1 \;\; \text{diminished reduction accepted} \end{cases} \qquad \text{(F-7,8)}$$

Case 3: $\delta_{KP} = 0$: $p = 0$:

$$\mathrm{Adj} = 1 \qquad \begin{pmatrix} \text{additional increase} \\ \text{not accepted} \end{pmatrix} \qquad \text{(F-9)}$$

Case 4: $\delta_{KP} < 0$: $p = 0$:

$$\mathrm{Adj} = \frac{1-\left(1+2(1-\mathrm{v})\dfrac{z_{u,2}(F_N)\rho}{1.96\rho_{\mathrm{crit}}}\right)\delta_{KP}}{1-\delta_{KP}} \qquad \begin{pmatrix} \text{additional increase} \\ \text{not accepted} \end{pmatrix}, \qquad \text{(F-10)}$$

where p specifies the accepted (fractional) amount by which true emission reductions (increases) can fall below (above) the committed level of reductions (increases); v approximates the net (effective) correlation between the absolute uncertainties ε_1 and ε_2 (cf. Section 3.3); and the other quantities are as explained above for the GSC #1 concept.

Result: The numerical result is given by Table 9 (see also Table F-1 in SOM_Math and worksheet *GSC_II 2a* in SOM_Num).

Table 9

Table 9 lists adjustment (Adj) values as a result of applying Eq. F-7 (Case 1), Eq. F-8 (Case 2), and Eq. F-9 and F-10 (Cases 3 and 4). They specify – based on the country's reported emissions change between base year and commitment year – the required adjustment of the country's emissions estimate in the commitment year or, equivalently, the *de facto* emissions reduction by this amount more than the country's commitment to remain in compliance with commitments. For any given δ_{KP} value (thus, ρ_{crit} value; see Eq. A-6 in Section 3.1), inventory uncertainty (ρ) is treated as parameter as well as the confidence $(1-\alpha)$ that true emission reductions (increases) will not fall below (above) the committed level of reductions (increases) by more than $p = 0.1$ (Cases 1 and 2: arbitrary choice of p) and $p = 0$ (Cases 3 and 4: additional emission increases are not accepted in the case of emission limitation). The confidence $(1-\alpha)$ is specified to be 0.9, 0.7 and 0.5. The correlation (v) is 0.75 (as in Section 3.3). The table shows that the GSC #2 concept is not easy to handle because it also requires strict enforcement under the KP. Emission reduction $(\delta_{KP} > 0)$ under the GSC #2 concept behaves, like under the GSC #1 concept, mirror-inverted to the Und concept as a consequence of nonuniform emission reduction commitments. That is, the GSC #2 concept would not run counter to the spirit of the KP if it were applied in the undershooting mode (adjustments must be compensated for by additional emission reductions). But it must be mentioned that, for the given set of parameters (notably, $p = 0.1$ and $v = 0.75$), the span between smallest and greatest Adj values is negligible.

4. Conclusions

We scrutinized six preparatory signal analysis techniques in a comparative mode. The purpose of this exercise is to provide a basis for discussing on how to go about dealing with uncertainty under the KP and its successor, and which of the technique(s) to eventually select. It was well-known that all techniques presented prior to and at the 1st International Workshop on Uncertainty in GHG Inventories perform differently (see below and Table 10 for a summary) but a rigorous quantitative and qualitative comparison was outstanding. In carrying out this comparative exercise, the aim was to understand the techniques holistically in the context of the KP, i.e., beyond their technical performance against mere disciplinary criteria. To this end we specified, e.g., the systems view adopted by a technique, the important assumptions that underlie a technique (and typically go unmentioned), and whether or not a technique contributes to the ultimate objective of the KP of reducing anthropogenic GHG emissions to the atmosphere measurably, i.e., above and beyond uncertainty.

The authors of these techniques all agree that uncertainty analysis is a key component of GHG emissions analysis although their perceptions range from using an investigation-focused approach to uncertainty analysis to only improve inventory quality to actually apply a technique, or a combination of techniques, to check compliance. All authors also agree that it makes a big difference in the framing of emission control policies whether or not uncertainty is considered. Of course, as a consequence of the techniques' different performance, they can have a different impact on the design and execution of such policies.

However, as it stands, a single best technique cannot yet be identified (and will, most likely, not exist); the main reason for this being that the techniques suffer from shortfalls that are not scientific but are related to the way the KP has been framed and implemented politically. As the two most important shortfalls on the side of policy-making can be identified (1) the overall neglect of uncertainty confronting experts with the situation that for most Annex B countries the agreed emission changes are of the same order of magnitude as the uncertainty that underlies their combined CO_2 equivalent emissions; and (2) the introduction of nonuniform emission reduction commitments. The techniques manifest these shortfalls differently:

Table 10

CRU and VT. These two concepts exhibit a dissimilarity between countries committed to emission reduction (stricter over more lenient Kyoto emission targets are favored) and emission limitation (more lenient over stricter Kyoto emission targets are favored).

Und and GSC #2. Varying δ_{KP}, the normalized emissions change committed under the KP, while keeping the relative uncertainty ρ and the risk α constant exhibits that under the Und concept countries that must comply with a small δ_{KP} (they exhibit a small modified emission limitation or reduction target δ_{mod}) are better off than countries that must comply with a great δ_{KP} (they exhibit a great modified emission limitation or reduction target δ_{mod}). Such a situation is not in line with the spirit of the KP. Emission reduction under the GSC #2 concept attempt to avoid this situation if applied in the undershooting mode. Countries that must comply with a great δ_{KP} (they exhibit a small Adj) are better off than countries that must comply with a small δ_{KP} (they exhibit a great Adj). But it must be mentioned that, for the given set of parameters (notably, $\rho = 0.1$ and $\nu = 0.75$), the span between smallest and greatest Adj values is negligible. So far, emission reduction and emission limitation under the GSC #2 are not treated uniformly. The GSC #2 concept still lacks clear guidelines as to whether or not, and to what extent, diminished (enhanced) emission reductions (increases) shall be accepted under these two regimes.

Und&VT and GSC #1. The Und&VT overcomes situations that run (Und concept) or can run counter to the spirit of the KP (GSC #1 and GSC #2 concepts if applied in the confidence mode). By requiring *a priori* detectable emission reductions, not limitations (see Cases 2–4 in Figure 4), the Und&VT concept corrects the Protocol's emission limitation or reduction targets through the introduction of an initial or obligatory undershooting so that the countries' emission signals become detectable before the countries are permitted to make economic use of their excess emission reductions. This, *de facto*, nullifies the politically agreed targets under the KP! However, we do not consider this a realistic scenario. By way of contrast, the GSC #1 concept builds on the notion of confidence, not detectability. If applied in the undershooting mode it would not run counter to the spirit of the KP. Nonetheless, it would enforce additional emission reductions, which would be smaller than those under the Und&VT concept but still be considerable and thus also difficult to sell politically. So far, emission reduction and emission limitation under the GSC #1 are not treated uniformly. The GSC #1 concept still lacks clear guidelines as to whether or not, and to what extent, excess emissions shall be accepted under these two regimes.

It appears very probable that the first shortfall (emission changes and uncertainty are of the same order of magnitude) will vanish soon with increasing political pressure to adopt a longer-lasting perspective and to realize greater emission reductions in the mid to long-term. However, we suggest that policy-makers revisit the second shortfall. If nonuniform, country-specific emission reduction commitments are favored, then these must be decided on the basis of a straightforward rule that applies equally and rigorously to all countries and should not be determined 'off the cuff'. Only then can scientists finalize their discussion and give meaningful feedback on which technique(s) to select for the preparatory analysis of uncertainty in the countries' emission changes—not least, which numerical advantages and disadvantages between countries we then have to accept and tolerate. Such an unsatisfying situation should be overcome in the next round of political 'post-Kyoto' negotiations. The knowledge to accomplish this is available.

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[1] For an overview of IIASA's emissions change-versus-uncertainty monitoring (reports and countries) see http://www.iiasa.ac.at/Research/FOR/unc_overview.html.

[2] At website http://www.iiasa.ac.at/Research/FOR/unc_prep.html click on *mathematical background* (referred to in the text as SOM_Math) and *numerical results* (referred to in the text as SOM_Num) to *Jonas et al. (2007)* under *Overview over six preparatory emissions change analysis techniques*.

[3] ISO country code: AT Austria; AU Australia; BE Belgium; BG Bulgaria; BY Belarus; CA Canada; CH Switzerland; CY Cyprus; CZ Czech Republic; DE Germany; DK Denmark; EC European Community; EE Estonia; ES Spain; FI Finland; FR France; GR Greece; HR Croatia; HU Hungary; IE Ireland; IS Iceland; IT Italy; JP Japan; LI Liechtenstein; LT Lithuania; LU Luxembourg; LV Latvia; MA Malta; MC Monaco; NL Netherlands; NO Norway; NZ New Zealand; PL Poland; PT Portugal; RO Romania; RU Russian Federation; SE Sweden; SI Slovenia; SK Slovak Republic; TR Turkey; UA Ukraine; UK United Kingdom; US United States.

[4] In their study Canadell *et al.* (2007: Table 1) show that, making use of global carbon budget data between 1959 and 2006, the efficiency of natural carbon sinks to remove atmospheric CO_2 has declined by about 2.5% per decade. Although this decline may look modest, it represents a mean net "source" to the atmosphere of 0.13 PgC yr^{-1} during 2000–2006. In comparison, a 5% reduction in the mean global fossil emissions during the same time period yields a net "sink" of 0.38 PgC yr^{-1}. Thus, deteriorating natural carbon sinks as a result of climate change or man's direct impact exhibit the potential to offset efforts to reduce fossil fuel emissions. This shows that man's impact on nature is indeed not negligible and stresses the need to look at the entire system, that is, to develop a full carbon systems view in which emissions and removals and their trends are monitored *in toto*.

[5] The CRU concept only considers uncertainty in the commitment year/period, not in the base year (i.e., formally $\varepsilon_1 = 0$). However, for reasons of comparability, we continue to abide by the condition of constant relative uncertainty.

[6] The absolute change in emissions is given by $|x_1 - x_2| = |\delta_{KP}| x_1$ (see Eq. A-2 in SOM_Math: Appendix A).

[7] The term 'verification time' was first used by Jonas *et al.* (1999) and by other authors since then. A more correct term is 'detection time' as signal detection does not imply verification. However, we continue to use the original term as we do not consider it inappropriate given that signal detection must, in the long-term, go hand-in-hand with bottom-up/top-down verification of emissions (see Jonas and Nilsson, 2007: Section 4).

[8] Applying Eq. C-7b in SOM_Math: Appendix C with $\varepsilon_{12} \approx 0.03$ (typically reported), $\delta_{KP} = 0.08$ (valid for many Annex B countries) and $\varepsilon_1 = \varepsilon_2 \approx 0.075$ (see right side of Table 1) results in $v \approx 0.79$.

[9] The Und&VT concept only considers uncertainty in the commitment year/period, not in the base year (i.e., formally $x_{t,1} = x_1$ and $v = 0$). However, for reasons of comparability, we continue to abide by the condition of constant relative uncertainty.

[10] Compliance with δ_{crit} ensures detectability in the commitment year. δ_{crit} is given by Eq. D-1 in SOM_Math: Appendix D; it is $\rho/(1+\rho)$ in the case $\delta_{KP} > 0$ (emission reduction) and $-\rho/(1-\rho)$ in the case $\delta_{KP} \leq 0$ (emission limitation). To overcome the dissimilarity between these two cases – δ_{crit} is smaller in absolute terms for emission reduction than for emission limitation – it adjusted by Eq. D-2 in SOM_Math: Appendix D to $\rho/(1+\rho)$ in the case $\delta_{KP} > 0$ (emission reduction) and $-\rho/(1+\rho)$ in the case $\delta_{KP} \leq 0$ (emission limitation); i.e., detectability as under emission reduction is declared as standard (in absolute terms).

[11] The two emissions adjustment methods presented by Gillenwater, Sussman and Cohen (GSC #1 and GSC #2) were meant to be applied in retrospect (Gillenwater *et al.*, 2007~~: Section 2.1~~). However, their

methods can also be used to generate information that one would like to discuss beforehand; that is, they can also be perceived as preparatory signal analysis techniques and thus be compared with the other four techniques discussed so far.

[12] The GSC #1 concept only considers uncertainty in the commitment year/period, not in the base year. However, for reasons of comparability, we continue to abide by the condition of constant relative uncertainty.

Acknowledgement

We like to thank the two anonymous reviewers for their valuable comments and suggestions to improve our paper.

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Acronyms and Nomenclature

Adj	adjustment
C&C	contraction and convergence
CH_4	methane
crit	critical (index)
CRU	critical relative uncertainty
CI	confidence interval
CO_2	carbon dioxide
FCCC	Framework Convention on Climate Change
F_N	standardized cumulative normal distribution
Gap	gap (index)
GHG	greenhouse gas
GSC	Gillenwater, Sussman and Cohen
HFC	hydrofluorocarbon
IPCC	Intergovernmental Panel on Climate Change
KP	Kyoto Protocol
KT	Kyoto (emissions) target
LULUCF	land use, land-use change, and forestry
N_2O	nitrous oxide
p	fractional amount
P	probability
PFC	perfluorocarbon
RelDiff	relative difference
SA	signal analysis
sd	standard deviation (index)
SF_6	sulphur hexafluoride
t	time ($t_1 \leq t \leq t_2$)
t	true (index)
u	upper (index)
U	undershooting
U_{GAP}	initial obligatory undershooting
UN	United Nations
Und	undershooting
VT	verification time
x	emissions
X	random variable
z	standardized emissions
Z	standardized random variable

α	risk ($0 \leq \alpha \leq 0.5$)
δ_{crit}	critical emission limitation or reduction
δ_{KP}	committed (normalized) emissions change under the KP
δ_{mod}	modified emission limitation or reduction target
δ'_{crit}	auxiliary variable
Δt	verification time
ε	absolute uncertainty

ρ	relative uncertainty
ρ_{crit}	critical relative uncertainty
υ	uncertainty correlation coefficient
1	referring to base year (index)
2	referring to commitment year (index)

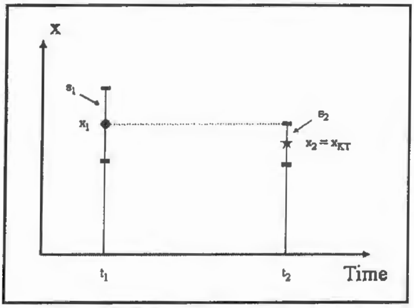


Figure 1: Illustration of the CRU concept ($\rho_1 = \rho_2$): The absolute change in emissions ($|x_1 - x_2| = |\delta_{KP}| x_1$) outstrips uncertainty at t_2.[6] Kyoto (emissions) target (KT). Source: Jonas *et al.* (2004a: Figure 8).

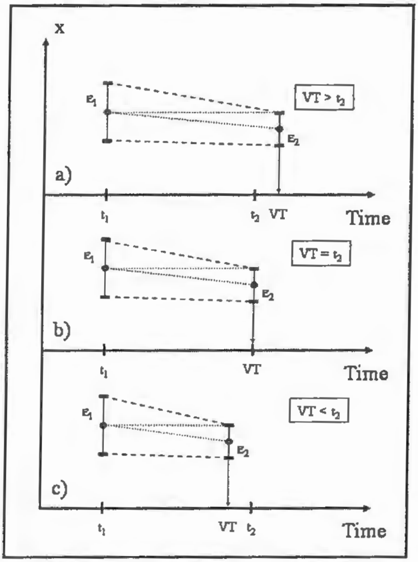


Figure 2: Illustration of the VT concept ($\rho_1 = \rho_2$): The absolute change in emissions ($|\Delta x(t)|$) outstrips uncertainty at **a)** $VT > t_2$, **b)** $VT = t_2$ and **c)** $VT < t_2$.[6] Source: Jonas *et al.* (2007: Figure 7), modified.

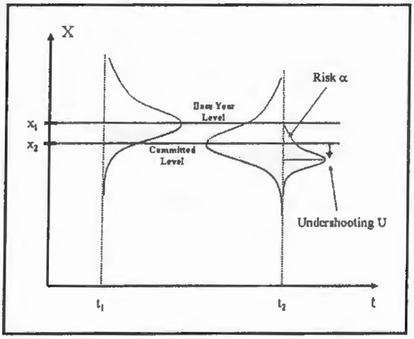


Figure 3: Illustration of the Und concept ($\rho_1 = \rho_2$) with the help of normal probability density functions: Undershooting helps to limit the risk α that countries overshoot their true emission limitation or reduction commitments. Source: Jonas *et al.* (2007: Figure 11); modified.

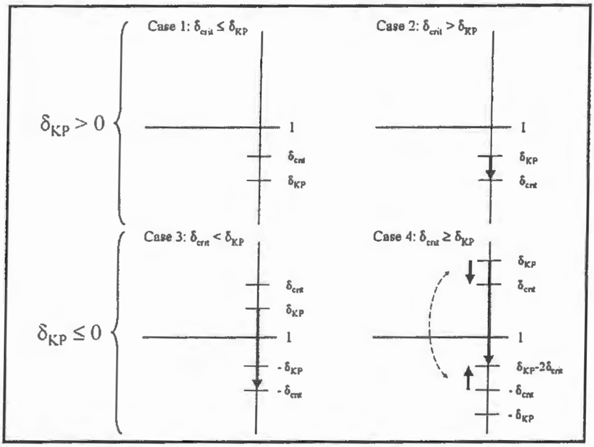


Figure 4: Illustration of the Und&VT concept ($\rho_1 = \rho_2$): It preserves risk as the strength of the Und concept and detectability as the strength of the VT concept. Depending on how δ_{crit} and δ_{KP} relate to each other, four cases can be distinguished (see text). These differ in terms of detectability (Cases 1 and 4) versus nondetectability (Cases 2 and 3) and an initial obligatory undershooting U_{Gap} that is introduced (Cases 2–4) to ensure that detectability of emission reductions, not increases, is given before Annex B countries are permitted to make economic use of potential excess emission reductions. Emission reduction: $\delta_{KP} > 0$; emission limitation: $\delta_{KP} \leq 0$. Source: Hamal and Jonas (2008b: Figure 4).

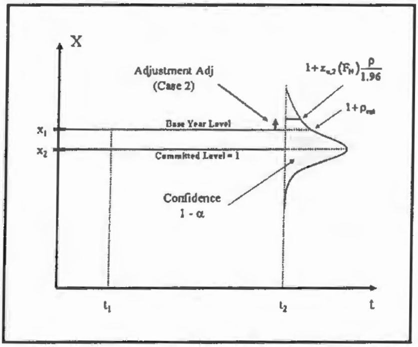


Figure 5: Illustration of the GSC #1 concept ($\rho_1 = \rho_2$) with the help of the standard normal probability density function: It allows specifying the confidence $(1-\alpha)$ via F_N that a country's true, but unknown, emissions comply with its Kyoto emissions target. Depending on whether or not excess emissions are accepted and favorable compliance conditions exist *a priori*, three cases are distinguished. Here, Case 2 is shown: Given an uncertainty of ρ%, this case requires adjusting a country's emissions estimate at t_2 upward if we want to be $(1-\alpha)$% confident that its true emissions do not exceed its Kyoto emissions target (here referred to as 1) by more than ρ_{crit}%. Emission reduction: $\delta_{KP} > 0$; emission limitation: $\delta_{KP} \leq 0$.

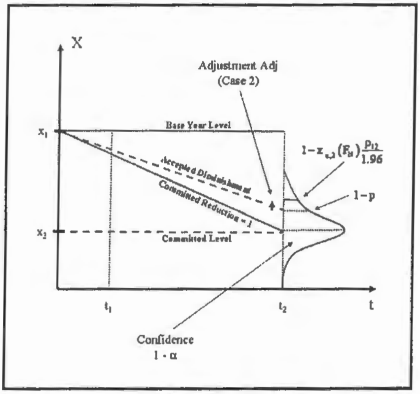
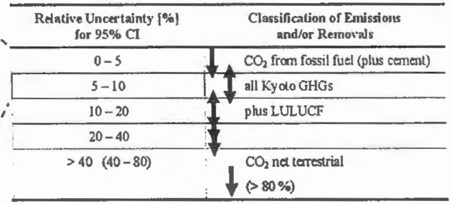


Figure 6: Illustration of the GSC #2 concept ($\rho_1 = \rho_2$) with the help of the standard normal probability density function: It allows specifying the confidence $(1-\alpha)$ via F_N that a country's true, but unknown, emissions change complies with its committed change. Depending on whether or not diminished reductions (additional increases) are accepted and favorable compliance conditions exist *a priori*, four cases are distinguished. Here, Case 2 is shown: Given an uncertainty of ρ%, this case requires adjusting a country's emissions estimate at t_2 upward if we want to be $(1-\alpha)$% confident its true emission reduction equals at least $(100-p)$% of the committed reduction (here referred to as 1). Emission reduction: $\delta_{KP} > 0$; emission limitation: $\delta_{KP} \leq 0$.

Table 1: **Left:** Countries included in Annex B to the Kyoto Protocol (KP) and their emission limitation and reduction commitments.[3] Sources: FCCC (1996: Decision 9/CP.2; 1998: Article 3.8, Annex B; 1999: Decision 11/CP.4; 2009: National Inventory Submissions 2008); COM (2006: Section 2.b). **Right:** Emissions and/or removals of greenhouse gases (GHGs), or combinations of GHGs, classified according to their relative uncertainty ranges. The bars of the arrows indicate the dominant uncertainty range for these emissions and removals, while the tops of the arrows point at the neighboring uncertainty ranges, which cannot be excluded but appear less frequently. LULUCF stands for the direct human-induced land use, land-use change, and forestry activities stipulated by Articles 3.3 and 3.4 under the KP (FCCC, 1998). The arrows are based on the total uncertainties that are reported annually by the Member States of the EU-25 (most recently: EEA, 2009) and the expertise available at IIASA's Forestry Program (cf. http://www.iiasa.ac.at/Research/FOR/unc_bottomup.html) and elsewhere (e.g., Watson *et al.*, 2000: Sections 2.3.7, 2.4.1; Penman *et al.*, 2003: Section 5.2). Source: Jonas and Nilsson (2007: Table 1), modified.

Country Group	Annex B Country	Base Year(s) for CO_2, CH_4, N_2O (for HFCs, PFCs, SF_6)	Commitment Period	KP Commitment %
1a	see below[1] see below[2]	1990 (1995) 1990 (1990)	2008–12	92
1b	RO	1989 (1989)	2008–12	
1c	BG	1988 (1995)	2008–12	
1d	SI	1986 (1995)	2008–12	
2	US[3]	1990 (1990)	2008–12	93
3a	JP CA	1990 (1995) 1990 (1990)	2008–12	94
3b	PL	1988 (1995)	2008–12	
3c	HU	1985–87 (1995)	2008–12	
4	HR	1990 (1995)	2008–12	95
5a	RU	1990 (1995)	2008–12	100
5b	NZ, UA	1990 (1990)	2008–12	
6	NO	1990 (1990)	2008–12	101
7	AU	1990 (1990)	2008–12	108
8	IS	1990 (1990)	2008–12	110



Relative Uncertainty [%] for 95% CI	Classification of Emissions and/or Removals
0 – 5	CO_2 from fossil fuel (plus cement)
5 – 10	all Kyoto GHGs
10 – 20	plus LULUCF
20 – 40	
> 40 (40 – 80)	CO_2 net terrestrial (> 80 %)

1) Country Group 1a: BE, CZ, DE, DK, EC (= EU-15; the EU-27 does not have a common Kyoto target), EE, ES, FI, GR, IE, LT, LU, LV, MC, NL, PT, SE, UK. Member States of the EU-27 but without individual Kyoto targets: CY, ML. Listed in the Convention's Annex I but not included in the Protocol's Annex B: BY and TR (BY and TR were not Parties to the Convention when the Protocol was adopted). BY requested becoming an Annex B country by amendment to the KP at CMP 2 in 2006. BY's base years and KP commitment are 1990 (1995) and 92%, respectively

2) Country Group 1a: AT, CH, FR, IT, LI, SK

3) Country Group 2: The US has indicated its intention not to ratify the KP. The US reports all its emissions with reference to 1990. However, information on 1990 in its national inventory submissions does not reflect or prejudge any decision that may be taken in relation to the use of 1995 as base year for hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6) in accordance with Article 3.8 of the KP

Table 2: The spatio-temporal and thematic conditions under which the six preparatory signal analysis techniques listed in Table 3 are applied and compared.

Dimension	Methodological Restriction	Focus in this study on
Spatial	none	National: countries as listed in Annex B to the KP (FCCC, 1998) The country scale is the principal reporting unit requested for reporting GHG emissions and removals under the KP. For convenience, we group these countries according to their (i) emission limitation or reduction commitments; and (ii) the base years for their emissions of CO_2, CH_4 and N_2O, resulting in eight country groups (see left side of Table 1). As the Annex B countries' emissions of CO_2, CH_4 and N_2O by far exceed those of the fluorinated (HCFs, PCFs, SF_6) gases, we use the combined emissions of CO_2, CH_4 and N_2O as reference.
Temporal	none	Two-points-in-time approach: base year (t_1) – commitment year/period (t_2) We use the year 2010 as commitment year with t_2 referring to the temporal average in net emissions over the commitment period 2008–2012.
Thematic	none	Annual CO_2 or CO_2 equivalent emissions: GHG emissions and/or removals of the six Kyoto GHGs as listed in Annex A to the KP (FCCC, 1998), individually or combined

Box 1: The relevant uncertainty terms and concepts that we refer to and make use of in our study.

Uncertainty (inventory definition): A general and imprecise term which refers to the lack of certainty (in inventory components) resulting from any causal factor such as unidentified sources and sinks, lack of transparency, etc. (Penman *et al.*, 2000: A3.19).

Total and trend uncertainty: The total (or level) uncertainty reflects our real diagnostic emissions accounting capabilities, that is, the uncertainty that underlies our past (base year) as well as our current accounting and that we will have to cope with in reality at some time in the future (commitment year/period). The trend uncertainty reflects the uncertainty of the difference in net emissions between two years (base year and/or commitment year/period) (Jonas and Nilsson, 2007: Section 4).

Confidence interval: The true value of the quantity for which the interval is to be estimated is a fixed but unknown constant, such as the annual total emissions in a given year for a given country. The confidence interval (CI) is a range that encloses the true value of this unknown fixed quantity with a specified confidence (probability). Typically, a CI of 95% is used in GHG inventories (IPCC, 2006: Section 3.1.3).

Relative uncertainty: To make all preparatory signal analysis techniques easily applicable, we build on relevant findings of earlier studies which suggest resolving relative uncertainty of inventory sources and sinks only in terms of intervals or classes and referring to their medians. Our definition of relative uncertainty classes (Class 1: 0–5%; Class 2: 5–10%; Class 3: 10–20%; Class 4: 20–40%; and Class 5: >40%) is arbitrary but appears robust. For further details we refer the reader to Jonas and Nilsson (2007: Section 2.4) and right side of Table 1.

Table 3: Major characteristics of the six preparatory signal analysis (SA) techniques compared in this study. 1: critical relative uncertainty concept (Gusti and Jęda, 2002); 2: verification time concept (Jonas *et al.*, 1999); 3: undershooting concept (Nahorski *et al.*, 2003); 4: undershooting and verification time concepts combined (Jonas *et al.*, 2004a); 5: Gillenwater, Sussman and Cohen #1 concept (Gillenwater *et al.*, 2007); 6: Gillenwater, Sussman and Cohen #2 concept (Gillenwater *et al.*, 2007). Sources: Jonas *et al.* (2004a: Table 3), Bun (2008: Table 2); modified.

Taken into account by the technique	**Preparatory SA Technique**					
	1	**2**	**3**	**4**	**5**	**6**
Trend uncertainty			✓			✓
Total uncertainty	✓	✓		✓	✓	
Intra-systems view			✓			✓
Intra-systems view but suited to support inter-systems (top-down) view	✓	✓		✓	✓	
Emissions difference (between t_1 and t_2 or at t_2)	✓		✓		✓	✓
Emissions gradient (between t_1 and t_2)		✓		✓		
Detectability of when an emission signal outstrips total uncertainty	✓	✓		✓		
Undershooting			✓	✓		
Upward adjustment of reported emissions					✓	✓
Risk with reference to the concept of significance			✓		✓	✓
Risk with reference to the concept of detectability				✓		

Table 4: The CRU concept (Eq. A-6) applied to Annex B countries. In the last column, we assess the hypothetical situation that the CRU concept had been applied prior to/in negotiating the KP. Note the dissimilarity between countries committed to emission reduction ($\delta_{KP} > 0$) and emission limitation ($\delta_{KP} \leq 0$) with the introduction of more lenient or stricter Kyoto emission targets.

Country Group	KP Commitment δ_{KP}[a] %	CRU ρ_{crit} %	If the CRU Concept had been applied
1a	8.0	8.7	a) Compliance with the Kyoto emission target: It must be expected that Annex B countries exhibit relative uncertainties in the range of 5–10% and above rather than below (excluding emissions/removals due to LULUCF and Kyoto mechanisms). Thus, it is impossible for a number of countries in groups 1–4 to meet the condition that their overall relative uncertainty is smaller than their CRU ($\rho < \rho_{crit}$). b) Towards more lenient Kyoto emission targets: To unambiguously attest a decrease in emissions, Annex B countries have to fulfill increasingly smaller CRUs. c) Towards stricter Kyoto emission targets: CRUs increase and can be met more easily.
1b			
1c			
1d			
2	7.0	7.5	
3a	6.0	6.4	
3b			
3c			
4	5.0	5.3	
--	4.0	4.2	
--	3.0	3.1	
--	2.0	2.0	
--	1.0	1.0	
5	0.0	0.0	a) Compliance with the Kyoto emission target: Same conclusion for countries in groups 5–8 as for countries committed to emission reduction (see a) above. b) Towards more lenient Kyoto emission targets: CRUs increase and can be met more easily. c) Towards stricter Kyoto emission targets: To unambiguously attest a decrease in emissions Annex B countries have to fulfill increasingly smaller CRUs.
6	-1.0	1.0	
--	-2.0	2.0	
--	-3.0	2.9	
--	-4.0	3.8	
--	-5.0	4.8	
--	-6.0	5.7	
--	-7.0	6.5	
7	-8.0	7.4	
--	-9.0	8.3	
8	-10.0	9.1	

[a] The countries' emission limitation and reduction commitments under the KP are expressed with the help of δ_{KP}, the normalized change in emissions between t_1 and t_2: $\delta_{KP} > 0$ — emission reduction; $\delta_{KP} \leq 0$ — emission limitation.

Table 5: The VT concept (Ineq. B-7a) applied to Annex B countries. The table has to be read as follows: The maximal allowable VT ($t_2 - t_1$) for an Annex B country is given for $\rho = \rho_{crit}$ (see second column). For a country of group 1a the maximal allowable VT is 20 years or 1, if normalized.

Normalized VTs equal to or smaller than 1 (see green fields for emission reduction and orange fields for emission limitation) are compatible with the KP, i.e., countries report with $\rho \le \rho_{crit}$; normalized VTs greater than 1 (see red fields) are not, i.e., countries report with $\rho > \rho_{crit}$. In the last column, we assess the hypothetical situation that the VT concept had been applied prior to/in negotiating the KP. Note the dissimilarity between countries committed to emission reduction ($\delta_{KP} > 0$) and emission limitation ($\delta_{KP} \le 0$) with the introduction of more lenient or stricter Kyoto emission targets.

Country Group	Max. Allow. VT[a] $t_2 - t_1$	KP Commit. δ_{KP}[b]	Normalized VTs if countries report with ρ =				If the VT Concept had been applied
			2.5	7.5	15	30	
	VT	%	%	%	%	%	
1a	20	8.0	0.3	0.9	[illegible]	[illegible]	<u>a) Compliance with the Kyoto emissions target:</u> It must be expected that Annex B countries exhibit relative uncertainties in the range of 5–10% and above rather than below (excluding emissions/ removals due to LULUCF and Kyoto mechanisms). Thus, it is impossible for a number of countries in groups 1–4 to meet the condition ρ < ρ_{crit} or, equivalently, achieve normalized VTs ≤ 1. <u>b) Towards more lenient Kyoto emission targets:</u> To unambiguously attest a decrease in emissions, Annex B countries have to fulfill increasingly smaller CRUs or, equivalently, find it more difficult to comply with normalized VTs ≤ 1. <u>c) Towards stricter Kyoto emission targets:</u> CRUs increase and can be met more easily or, equivalently, compliance with normalized VTs ≤ 1 becomes less difficult.
1b	22						
1c	21						
1d	24						
2	20	7.0	0.3	< 1.0	[illegible]	[illegible]	
3a	20	6.0	0.4	[illegible]	[illegible]	[illegible]	
3b	24						
3c	22						
4	20	5.0	0.5	[illegible]	[illegible]	[illegible]	
...	...	4.0	0.6	[illegible]	[illegible]	[illegible]	
...	...	3.0	0.8	[illegible]	[illegible]	[illegible]	
...	...	2.0	[illegible]	[illegible]	[illegible]	[illegible]	
...	...	1.0	[illegible]	[illegible]	[illegible]	[illegible]	
5	20	0.0	[illegible]				<u>a) Compliance with the Kyoto emissions target:</u> Same conclusion for countries in groups 5–8 as for countries committed to emission reduction (see a) above). <u>b) Towards more lenient Kyoto emission targets:</u> CRUs increase and can be met more easily or, equivalently, compliance with normalized VTs ≤ 1 becomes less difficult. <u>c) Towards stricter Kyoto emission targets.</u> To unambiguously attest a decrease in emissions, Annex B countries have to fulfill increasingly smaller CRUs or, equivalently, find it more difficult to comply with normalized VTs ≤ 1.
6	20	-1.0	[illegible]	[illegible]	[illegible]	[illegible]	
...	...	-2.0	[illegible]	[illegible]	[illegible]	[illegible]	
...	...	-3.0	0.9	[illegible]	[illegible]	[illegible]	
...		-4.0	0.6	[illegible]	[illegible]	[illegible]	
...	...	-5.0	0.5	[illegible]	[illegible]	[illegible]	
...	...	-6.0	0.4	[illegible]	[illegible]	[illegible]	
...	...	-7.0	0.4	[illegible]	[illegible]	[illegible]	
7	20	-8.0	0.3	[illegible]	[illegible]	[illegible]	
...	...	-9.0	0.3	0.9	[illegible]	[illegible]	
8	20	-10.0	0.3	0.8	[illegible]	[illegible]	

[a] The maximal allowable VT is calculated for each country group as the difference between 2010 (as the temporal mean over the commitment period 2008–2012) and its base year, or mean base year, for its emissions of CO_2, CH_4 and N_2O (cf. also Table 2).

[b] The countries' emission limitation and reduction commitments under the KP are expressed with the help of δ_{KP}, the normalized change in emissions between t_1 and t_2. $\delta_{KP} > 0$ — emission reduction; $\delta_{KP} \le 0$ — emission limitation

Table 6: The Und concept (Eq. C-15 in combination with Eq. C-18 and a correlation of $v = 0.75$ typical for currently reported uncertainties) applied to Annex B countries. The table lists modified emission limitation or reduction targets δ_{mod} for all Annex B countries, where the '$x_{t,2}$-greater-than-$(1-\delta_{KP})x_{t,1}$' risk α is specified to be 0, 0.1, 0.3 and 0.5. If an Annex B country complies with its emission limitation or reduction commitment ($x_2 = (1-\delta_{KP})x_1$), the risk that its true, but unknown, emissions $x_{t,2}$ are equal to or greater than its true, but unknown, target $(1-\delta_{KP})x_{t,1}$ is 50%. Undershooting decreases this risk. For instance, a country of group 1 has committed itself to reduce its net emissions by 8%. Reporting with a 7.5% relative uncertainty, it needs to reduce emissions by 11.4% to decrease the risk from 50% to 0%. In the last column, we assess the hypothetical situation that the Und concept had been applied prior to/in negotiating the KP. Note the unfavorable situation, which arises when δ_{KP} varies while p and α are kept constant.

Country Group	KP Commit.	Modified Emission Limitation or Reduction Target δ_{mod} in % for					If the Und Concept had been applied
	δ_{KP}[a] %	α = 1	ρ = 2.5 %	7.5 %	15 %	30 %	
1a–d	8.0	0.0	9.1	11.4	14.7	20.8	<u>a) For given δ_{KP} and α:</u> The greater ρ, the greater the modified emission reduction target δ_{mod} must be to keep the ' $x_{t,2}$ -greater-than- $(1-\delta_{KP})x_{t,1}$ ' risk α at a constant level (see, e.g., country group 1: third line: δ_{mod} values for $\alpha = 0.3$). <u>b) For given ρ and α:</u> The smaller δ_{KP} , the smaller the modified emission reduction target δ_{mod} can be to keep the ' $x_{t,2}$ -greater-than- $(1-\delta_{KP})x_{t,1}$ ' risk α at a constant level (see, e.g., δ_{mod} values for $\rho = 7.5\%$ and $\alpha = 0.3$). As a consequence, countries that must comply with a small δ_{KP} (they exhibit a small δ_{mod}) are better off than countries that must comply with a great δ_{KP} (they exhibit a great δ_{mod}).
		0.1	8.9	10.7	13.4	18.4	
		0.3	8.5	9.4	10.7	13.4	
		0.5	8.0	8.0	8.0	8.0	
2	7.0	0.0	8.2	10.4	13.7	20.0	
		0.1	7.9	9.7	12.4	17.5	
		0.3	7.5	8.4	9.7	12.4	
		0.5	7.0	7.0	7.0	7.0	
3a–c	6.0	0.0	7.2	9.5	12.8	19.1	
		0.1	6.9	8.8	11.5	16.6	
		0.3	6.5	7.4	8.8	11.5	
		0.5	6.0	6.0	6.0	6.0	
4	5.0	0.0	6.2	8.5	11.9	18.3	
		0.1	5.9	7.8	10.5	15.8	
		0.3	5.5	6.4	7.8	10.5	
		0.5	5.0	5.0	5.0	5.0	
---	4.0	0.0	5.2	7.5	10.9	17.4	
		0.1	5.0	6.8	9.6	14.9	
		0.3	4.5	5.4	6.8	9.6	
		0.5	4.0	4.0	4.0	4.0	
---	3.0	0.0	4.2	6.6	10.0	16.5	
		0.1	4.0	5.9	8.7	14.0	
		0.3	3.5	4.4	5.9	8.7	
		0.5	3.0	3.0	3.0	3.0	
---	2.0	0.0	3.2	5.6	9.1	15.7	
		0.1	3.0	4.9	7.7	13.1	
		0.3	2.5	3.5	4.9	7.7	
		0.5	2.0	2.0	2.0	2.0	
---	1.0	0.0	2.2	4.6	8.2	14.8	
		0.1	2.0	3.9	6.8	12.2	
		0.3	1.5	2.5	3.9	6.8	
		0.5	1.0	1.0	1.0	1.0	

[a] The countries' emission limitation and reduction commitments under the KP are expressed with the help of δ_{KP} , the normalized change in emissions between t_1 and t_2 : $\delta_{KP} > 0$ — emission reduction; $\delta_{KP} \leq 0$ — emission limitation.

Table 6 continued:

5	**0.0**	**0.0**	**1.2**	**3.7**	**7.2**	**14.0**	a) For given δ_{KP} and α: Same conclusion for country groups 5–8 as for countries committed to emission reduction (see a) above).
		0.1	**1.0**	**3.0**	**5.8**	**11.3**	
		0.3	**0.5**	**1.5**	**3.0**	**5.8**	
		0.5	**0.0**	**0.0**	**0.0**	**0.0**	
6	**-1.0**	**0.0**	**0.3**	**2.7**	**6.3**	**13.1**	b) For given ρ and α: Same conclusion for country groups 5–8 as for countries committed to emission reduction (see b) above).
		0.1	**0.0**	**2.0**	**4.9**	**10.4**	
		0.3	**-0.5**	**0.5**	**2.0**	**4.9**	
		0.5	**-1.0**	**-1.0**	**-1.0**	**-1.0**	
---	-2.0	0.0	-0.7	1.8	5.4	12.2	
		0.1	-1.0	1.0	3.9	9.5	
		0.3	-1.5	-0.5	1.0	3.9	
		0.5	-2.0	-2.0	-2.0	-2.0	
---	-3.0	0.0	-1.7	0.8	4.4	11.4	
		0.1	-2.0	0.0	3.0	8.7	
		0.3	-2.5	-1.5	0.0	3.0	
		0.5	-3.0	-3.0	-3.0	-3.0	
---	-4.0	0.0	-2.7	-0.2	3.5	10.5	
		0.1	-3.0	-0.9	2.1	7.8	
		0.3	-3.5	-2.5	-0.9	2.1	
		0.5	-4.0	-4.0	-4.0	-4.0	
---	-5.0	0.0	-3.7	-1.1	2.6	9.7	
		0.1	-4.0	-1.9	1.1	6.9	
		0.3	-4.5	-3.4	-1.9	1.1	
		0.5	-5.0	-5.0	-5.0	-5.0	
---	-6.0	0.0	-4.7	-2.1	1.7	8.8	
		0.1	-4.9	-2.9	0.2	6.0	
		0.3	-5.5	-4.4	-2.9	0.2	
		0.5	-6.0	-6.0	-6.0	-6.0	
---	-7.0	0.0	-5.7	-3.1	0.7	7.9	
		0.1	-5.9	-3.8	-0.8	5.1	
		0.3	-6.5	-5.4	-3.8	-0.8	
		0.5	-7.0	-7.0	-7.0	-7.0	
7	**-8.0**	**0.0**	**-6.7**	**-4.0**	**-0.2**	**7.1**	
		0.1	**-6.9**	**-4.8**	**-1.7**	**4.2**	
		0.3	**-7.5**	**-6.4**	**-4.8**	**-1.7**	
		0.5	**-8.0**	**-8.0**	**-8.0**	**-8.0**	
---	-9.0	0.0	-7.6	-5.0	-1.1	6.2	
		0.1	-7.9	-5.8	-2.7	3.3	
		0.3	-8.5	-7.4	-5.8	-2.7	
		0.5	-9.0	-9.0	-9.0	-9.0	
8	**-10.0**	**0.0**	**-8.6**	**-6.0**	**-2.0**	**5.3**	
		0.1	**-8.9**	**-6.7**	**-3.6**	**2.5**	
		0.3	**-9.5**	**-8.4**	**-6.7**	**-3.6**	
		0.5	**-10.0**	**-10.0**	**-10.0**	**-10.0**	

Table 7: The Und&VT concept (Eq. C-15 in combination with: Eq. D-5 [Case 1: green fields], Eq. D-8 to D-9 [Case 2: red fields], Eq. D-12 to D-13 [Case 3: red fields], and Eq. D-16 to D-18 [Case 4: orange fields]) applied to Annex B countries. The table lists modified emission limitation or reduction targets δ_{mod} for all Annex B countries, where the '$x_{t,2}$-greater-than-$(1-\delta_{KP})x_{t,1}$' risk α (Case 1), the '$x_{t,2}$-greater-than-$(1-\delta_{crit})x_{t,1}$' risk α (Case 2), the '$x_{t,2}$-greater-than-$(1+\delta_{crit})x_{t,1}$' risk α (Case 3), and the '$x_{t,2}$-greater-than-$(1-(\delta_{KP}-2\delta_{crit}))x_{t,1}$' risk α (Case 4), respectively, are specified to be 0, 0.1, 0.3 and 0.5. In the last column, we assess the hypothetical situation that the Und&VT concept had been applied prior to/in negotiating the KP. The Und&VT concept rectifies Cases 2 and 3, the cases of nondetectability (before correction), that is, the unfavourable situation under the Und concept under which countries complying with a small δ_{KP} exhibit a small δ_{mod}, while countries complying with a great δ_{KP} exhibit a great δ_{mod} (cf. Table 6).

Country Group	KP Commit. δ_{KP}[a] %	Modified Emission Limitation or Reduction Target δ_{mod} in % for α = 1	ρ = 2.5 %	7.5 %	15 %	30 %	If the Und&VT Concept had been applied
1a–d	8.0	0.0	10.2	14.4	24.1	40.8	<u>Case 1 (green-colored area): $\delta_{mod} \le \delta_{KP}$:</u> No necessity to introduce U_{cap}, the δ_{mod} values from Table 6 are still valid. <u>Case 2 (red-colored area): $\delta_{mod} > \delta_{KP}$:</u> Increase of δ_{KP} by U_{cap} to reach δ_{mod}, the relevant reference for undershooting. Undershooting only depends on ρ and α and not anymore on δ_{KP} (see Eq. D-8 to D-9 in combination with Eq. C-15). This explains why δ_{mod} appears uniform for given ρ and α. Thus, the Und&VT concept rectifies the Und concept under which countries complying with a small δ_{KP} exhibit a small δ_{mod}, while countries complying with a great δ_{KP} exhibit a great δ_{mod} (cf. Table 6).
		0.1	9.8	13.2	22.4	38.0	
		0.3	8.9	10.7	18.5	31.3	
		0.5	8.0	8.0	15.0	23.1	
2	7.0	0.0	9.3	13.5	24.1	40.8	
		0.1	8.8	12.3	22.4	38.0	
		0.3	7.9	9.7	18.5	31.3	
		0.5	7.0	7.0	15.0	23.1	
3a–c	6.0	0.0	8.3	13.5	24.1	40.8	
		0.1	7.8	12.5	22.4	38.0	
		0.3	6.9	9.7	18.5	31.3	
		0.5	6.0	7.0	15.0	23.1	
4	5.0	0.0	7.3	13.5	24.1	40.8	
		0.1	6.9	12.5	22.4	38.0	
		0.3	5.9	9.7	18.5	31.3	
		0.5	5.0	7.0	15.0	23.1	
...	4.0	0.0	6.3	13.5	[illegible]	40.8	
		0.1	5.9	12.5	[illegible]	38.0	
		0.3	5.0	[illegible]	[illegible]	31.3	
		0.5	4.0	7.0	[illegible]	23.1	
...	3.0	0.0	5.4	13.5	24.1	[illegible]	
		0.1	4.9	12.5	22.4	[illegible]	
		0.3	4.0	[illegible]	18.5	[illegible]	
		0.5	3.0	7.0	15.0	[illegible]	
...	2.0	0.0	[illegible]	13.5	24.1	[illegible]	
		0.1	[illegible]	[illegible]	22.4	38.0	
		0.3	[illegible]	[illegible]	18.0	31.3	
		0.5	[illegible]	7.0	15.0	23.1	
...	1.0	0.0	[illegible]	13.5	24.4	40.8	
		0.1	[illegible]	12.5	22.4	38.0	
		0.3	[illegible]	9.7	18.5	31.3	
		0.5	[illegible]	7.0	15.0	23.1	

---

[a] The countries' emission limitation and reduction commitments under the KP are expressed with the help of δ_{KP}, the normalized change in emissions between t_1 and t_2: $\delta_{KP} > 0$ — emission reduction; $\delta_{KP} \le 0$ — emission limitation.

Table 7 continued:

5	**0.0**	**0.0**	4.8	13.5	24.4	40.8
		0.1	4.4	12.2	22.4	38.0
		0.3	3.4	9.7	18.0	31.3
		0.5	2.4	7.0	13.0	23.1
6	**-1.0**	**0.0**	4.8	13.5	24.4	40.8
		0.1	4.4	12.2	22.4	38.0
		0.3	3.4	9.7	18.0	31.3
		0.5	2.4	7.0	13.0	23.1
...	-2.0	0.0	4.8	13.5	24.4	40.8
		0.1	4.4	12.2	22.4	38.0
		0.3	3.4	9.7	18.0	31.3
		0.5	2.4	7.0	13.0	23.1
...	-3.0	0.0	4.3	13.5	24.4	40.8
		0.1	3.8	12.2	22.4	38.0
		0.3	2.8	9.7	18.0	31.3
		0.5	1.9	7.0	13.0	23.1
...	-4.0	0.0	3.3	13.5	24.4	40.8
		0.1	2.8	12.2	22.4	38.0
		0.3	1.9	9.7	18.0	31.3
		0.5	0.9	7.0	13.0	23.1
...	-5.0	0.0	2.3	13.5	24.4	40.8
		0.1	1.8	12.2	22.4	38.0
		0.3	0.9	9.7	18.0	31.3
		0.5	-0.1	7.0	13.0	23.1
...	-6.0	0.0	1.3	13.5	24.4	40.8
		0.1	0.9	12.2	22.4	38.0
		0.3	-0.1	9.7	18.0	31.3
		0.5	-1.1	7.0	13.0	23.1
...	-7.0	0.0	0.4	13.4	24.4	40.8
		0.1	-0.1	12.2	22.4	38.0
		0.3	-1.1	9.7	18.0	31.3
		0.5	-2.1	7.0	13.0	23.1
7	**-8.0**	**0.0**	**-0.6**	**12.5**	**24.4**	**40.8**
		0.1	**-1.1**	**11.3**	**22.4**	**38.0**
		0.3	**-2.1**	**8.7**	**18.0**	**31.3**
		0.5	**-3.1**	**6.0**	**13.0**	**23.1**
...	-9.0	0.0	-1.6	11.6	24.4	40.8
		0.1	-2.1	10.3	22.4	38.0
		0.3	-3.1	7.7	18.0	31.3
		0.5	-4.1	5.0	13.0	23.1
8	**-10.0**	**0.0**	**-2.6**	**10.7**	**24.4**	**40.8**
		0.1	**-3.1**	**9.4**	**22.4**	**38.0**
		0.3	**-4.1**	**6.8**	**18.0**	**31.3**
		0.5	**-5.1**	**4.0**	**13.0**	**23.1**

Case 3 (red-colored area): $\delta_{crit} < \delta_{KP}$:
Increase of δ_{KP} by U_{Cap} to reach $-\delta_{crit}$, the relevant reference for undershooting. Undershooting only depends on ρ and α and not anymore on δ_{KP} (see Eq. D-12 to D-13 in combination with Eq. C-15). This explains why δ_{mod} appears uniform for a given ρ and α. Thus, the Und&VT concept rectifies the Und concept under which countries complying with a small δ_{KP} exhibit a small δ_{mod}, while countries complying with a great δ_{KP} exhibit a great δ_{mod} (cf. Table 6).

Case 4 (orange-colored area): $\delta_{crit} \geq \delta_{KP}$:
Increase of δ_{KP} by U_{Cap} to reach $\delta_{KP} - 2\delta_{crit}$, the relevant reference for undershooting. In contrast to Case 3 ($\delta_{crit} < \delta_{KP}$) above, undershooting still depends on δ_{KP} (see Eq. D-16 to D-18 in combination with Eq. C-15). This is a consequence of how the undershooting is realized: detectability on the emissions limitation side is used to decrease the reference for undershooting ($\delta_{KP} - 2\delta_{crit}$) on the emissions reduction side.

Table 8: The GSC #1 concept (Eq. E-7 [Case 1: green fields; here, the $\text{Adj} < 1$ values have not been set to 1], Eq. E-8 [Case 2: orange fields], and Eq. E-9 [Case 3: red fields]) applied to Annex B countries. The table lists the required adjustments Adj for all Annex B countries, where the confidence $(1-\alpha)$ that true emissions do not exceed (overshoot) target emissions by more than $p = \delta_{crit}$ (Cases 1 and 2) and $p = 0$ (Case 3) is specified to be 0.9, 0.7 and 0.5. In the last column, we assess the hypothetical situation that the GSC #1 concept had been applied prior to/in negotiating the KP. Note the potentially unfavorable situation in Case 2, which arises when δ_{KP} varies while ρ and $(1-\alpha)$ are kept constant.

Country Group	KP Commit.	CRU	Adjustment Factor Adj (absolute) for					If the GSC #1 Concept had been applied
	δ_{KP}*	ρ_{crit}	1 - α =	ρ =				
				2.5	7.5	15	30	
	%	%	1	%	%	%	%	
1a–d	8.0	8.7	1.0					<u>Case 1 (green-colored area): $\rho \approx \delta_{crit}$, Adj ≤ 1:</u> Favorable compliance conditions; no need for an adjustment (Adj can be set to 1). <u>Case 2 (orange-colored area): $\rho \approx \delta_{crit}$, Adj > 1:</u> The greater ρ, the uncertainty surrounding the emissions inventory estimate, or the greater $(1-\alpha)$, the degree of confidence that is required, the greater the adjustment Adj. However, the smaller δ_{KP}, the greater the adjustment Adj to keep the confidence $(1-\alpha)$ at a constant level (see, e.g., Adj values for $\rho = 15\%$ and $1-\alpha = 0.9$). As a consequence, countries that must comply with a great δ_{KP} (they exhibit a small Adj) are better off than countries that must comply with a small δ_{KP} (they exhibit a great Adj). This is only true if adjustments must be compensated for by additional emission reductions (undershooting mode). However, the opposite is true if this compensation is not compulsory and adjustments are only used to establish a country comparison in terms of confidence (confidence mode) without compulsory undershooting. In the latter case countries that must comply with a small δ_{KP} (they exhibit a great Adj) are better off than countries that must comply with a great δ_{KP} (they exhibit a small Adj).
			0.9	0.935	0.965	1.018	1.109	
			0.7	0.926	0.938	0.957	0.994	
			0.5	0.920	0.920	0.920	0.920	
2	7.0	7.5	1.0					
			0.9	0.945	0.976	1.028	1.112	
			0.7	0.936	0.949	0.967	1.004	
			0.5	0.930	0.930	0.930	0.930	
3a–e	6.0	6.4	1.0					
			0.9	0.955	0.986	[illegible]	1.124	
			0.7	0.946	0.959	0.978	1.015	
			0.5	0.940	0.940	0.940	0.940	
4	5.0	5.3	1.0					
			0.9	0.966	0.997	[illegible]	1.136	
			0.7	0.956	0.969	0.988	1.026	
			0.5	0.950	0.950	0.950	0.950	
…	4.0	4.2	1.0					
			0.9	0.976	1.007	[illegible]	[illegible]	
			0.7	0.966	0.979	0.997	1.037	
			0.5	0.960	0.960	0.960	0.960	
…	3.0	3.1	1.0					
			0.9	0.986	1.018	[illegible]	1.160	
			0.7	0.976	0.989	1.009	1.048	
			0.5	0.970	0.970	0.970	0.970	
…	2.0	2.0	1.0					
			0.9	0.996	1.028	[illegible]	1.172	
			0.7	0.987	1.000	1.019	1.059	
			0.5	0.980	0.980	0.980	0.980	
…	1.0	1.0	1.0					
			0.9	1.006	1.039	[illegible]	[illegible]	
			0.7	0.997	1.010	1.030	1.069	
			0.5	0.990	0.990	0.990	0.990	

* The countries' emission limitation and reduction commitments under the KP are expressed with the help of δ_{KP}, the normalized change in emissions between t_1 and t_2: $\delta_{KP} > 0$ — emission reduction; $\delta_{KP} \leq 0$ — emission limitation.

Table 8 continued:

5	**0.0**	**0.0**	**1.0**	[illegible]	[illegible]	[illegible]	[illegible]
			0.9	[illegible]	[illegible]	[illegible]	[illegible]
			0.7	[illegible]	[illegible]	[illegible]	[illegible]
			0.5	[illegible]	[illegible]	[illegible]	[illegible]
6	**-1.0**	**1.0**	**1.0**	[illegible]	[illegible]	[illegible]	[illegible]
			0.9	[illegible]	[illegible]	[illegible]	[illegible]
			0.7	[illegible]	[illegible]	[illegible]	[illegible]
			0.5	[illegible]	1.001	[illegible]	[illegible]
...	-2.0	2.0	1.0	[illegible]	[illegible]	[illegible]	[illegible]
			0.9	[illegible]	[illegible]	[illegible]	[illegible]
			0.7	[illegible]	[illegible]	[illegible]	[illegible]
			0.5	[illegible]	[illegible]	[illegible]	[illegible]
...	-3.0	2.9	1.0	[illegible]	[illegible]	[illegible]	[illegible]
			0.9	[illegible]	[illegible]	[illegible]	[illegible]
			0.7	[illegible]	[illegible]	[illegible]	[illegible]
			0.5	[illegible]	[illegible]	[illegible]	[illegible]
...	-4.0	3.8	1.0	[illegible]	[illegible]	[illegible]	[illegible]
			0.9	[illegible]	[illegible]	[illegible]	[illegible]
			0.7	[illegible]	[illegible]	[illegible]	[illegible]
			0.5	[illegible]	[illegible]	[illegible]	[illegible]
...	-5.0	4.8	1.0	[illegible]	[illegible]	[illegible]	[illegible]
			0.9	[illegible]	[illegible]	[illegible]	[illegible]
			0.7	[illegible]	[illegible]	[illegible]	[illegible]
			0.5	[illegible]	[illegible]	[illegible]	[illegible]
...	-6.0	5.7	1.0	[illegible]	[illegible]	[illegible]	[illegible]
			0.9	[illegible]	[illegible]	[illegible]	[illegible]
			0.7	[illegible]	[illegible]	[illegible]	[illegible]
			0.5	[illegible]	[illegible]	[illegible]	[illegible]
...	-7.0	6.5	1.0	[illegible]	[illegible]	[illegible]	[illegible]
			0.9	[illegible]	[illegible]	[illegible]	[illegible]
			0.7	[illegible]	[illegible]	[illegible]	[illegible]
			0.5	[illegible]	[illegible]	[illegible]	[illegible]
7	**-8.0**	**7.4**	**1.0**	[illegible]	[illegible]	[illegible]	[illegible]
			0.9	[illegible]	[illegible]	[illegible]	[illegible]
			0.7	[illegible]	[illegible]	[illegible]	[illegible]
			0.5	[illegible]	[illegible]	[illegible]	[illegible]
...	-9.0	8.3	1.0	[illegible]	[illegible]	[illegible]	[illegible]
			0.9	[illegible]	[illegible]	[illegible]	[illegible]
			0.7	[illegible]	[illegible]	[illegible]	[illegible]
			0.5	[illegible]	[illegible]	[illegible]	[illegible]
8	**-10.0**	**9.1**	**1.0**	[illegible]	[illegible]	[illegible]	[illegible]
			0.9	[illegible]	[illegible]	[illegible]	[illegible]
			0.7	[illegible]	[illegible]	[illegible]	[illegible]
			0.5	[illegible]	[illegible]	[illegible]	[illegible]

Case 3 (red-colored area): $p = 0$, $Adj \geq 1$: The fractional factor p which allows that true emissions can exceed target emissions commitments is unconditionally set to 0. No excess emissions, i.e., additional emission increases are accepted. As a consequence, all countries exhibit identical adjustments Adj.

Table 9: The GSC #2 concept (Eq. F-7 [Case 1: green fields; here, the $\mathrm{Adj} < 1$ values have not been set to 1], Eq. F-8 [Case 2: orange fields], and Eq. F-9 and F-10 [Cases 3 and 4: red fields]) applied to Annex B countries. The table lists the required adjustments Adj for all Annex B countries, where the confidence $(1-\alpha)$ that true emission reductions (increases) will not fall below (above) the committed level of reductions (increases) by more than $\rho = 0.1$ (Cases 1 and 2) and $\rho = 0$ (Cases 3 and 4) is specified to be 0.9, 0.7 and 0.5. The correlation ν is 0.75 (as in Section 3.3). In the last column, we assess the hypothetical situation that the GSC #2 concept had been applied prior to/in negotiating the KP. Note the potentially unfavorable situation in Case 2, which arises when δ_{KP} varies while ρ and $(1-\alpha)$ are kept constant. However, for the given set of parameters (notably, $\rho = 0.1$ and $\nu = 0.75$) the span between the smallest and greatest Adj values is negligible.

Country Group	KP Commit.	CRU	Adjustment Factor Adj (absolute) for					If the GSC #2 Concept had been applied
			$1-\alpha =$	$\rho =$				
	δ_{KP}[a]	δ_{crit}		2.5	7.5	15	30	
	%	%	1	%	%	%	%	
1a–d	8.0	8.7	1.0	[illegible]	[illegible]	[illegible]	[illegible]	Case 1 (green-colored area): $\rho = 0.1$, Adj ≤ 1: Favorable compliance conditions; no need for an adjustment (Adj can be set to 1). Case 2 (orange-colored area): $\rho = \delta_{crit}$, Adj > 1: The greater ρ, the uncertainty surrounding the emissions inventory estimate, or the greater $(1-\alpha)$, the degree of confidence that is required, the greater the adjustment Adj. However, the smaller δ_{KP}, the greater the adjustment Adj to keep the confidence $(1-\alpha)$ at a constant level (see, e.g., Adj values for $\rho = 15\%$ and $1-\alpha = 0.9$). As a consequence, countries that must comply with a great δ_{KP} (they exhibit a small Adj) are better off than countries that must comply with a small δ_{KP} (they exhibit a great Adj). This is only true if adjustments must be compensated for by additional emission reductions (undershooting mode). But it must be mentioned that, for the given set of parameters (notably, $p = 0.1$ and $v = 0.75$), the span between smallest and greatest Adj values is negligible. However, the opposite is true if this compensation is not compulsory and adjustments are only used to establish a country comparison in terms of confidence (confidence mode) without compulsory undershooting. In the latter case countries that must comply with a small δ_{KP} (they exhibit a great Adj) are better off than countries that must comply with a great δ_{KP} (they exhibit a small Adj).
			0.9	0.999	1.016	1.046	[illegible]	
			0.7	0.995	1.001	1.011	1.031	
			0.5	0.991	0.991	0.991	0.991	
2	7.0	7.5	1.0	[illegible]	[illegible]	[illegible]	[illegible]	
			0.9	1.001	1.017	1.041	1.093	
			0.7	0.996	1.002	1.012	1.033	
			0.5	0.993	0.993	0.993	0.993	
3a–c	6.0	6.4	1.0	[illegible]	[illegible]	[illegible]	[illegible]	
			0.9	1.002	1.018	1.042	1.091	
			0.7	0.997	1.004	1.014	1.034	
			0.5	0.994	0.994	0.994	0.994	
4	5.0	5.3	1.0	[illegible]	[illegible]	[illegible]	[illegible]	
			0.9	1.003	1.019	1.044	1.092	
			0.7	0.998	1.005	1.015	1.035	
			0.5	0.995	0.995	0.995	0.995	
---	4.0	4.2	1.0	[illegible]	[illegible]	[illegible]	[illegible]	
			0.9	1.004	1.020	1.045	[illegible]	
			0.7	0.999	1.006	1.015	[illegible]	
			0.5	0.996	0.996	0.996	0.996	
---	3.0	3.1	1.0	[illegible]	[illegible]	[illegible]	[illegible]	
			0.9	1.005	1.021	1.046	1.097	
			0.7	1.000	1.006	1.019	[illegible]	
			0.5	0.997	0.997	0.997	0.997	
---	2.0	2.0	1.0	[illegible]	[illegible]	[illegible]	[illegible]	
			0.9	1.006	1.022	1.047	[illegible]	
			0.7	1.001	1.008	1.018	[illegible]	
			0.5	0.998	0.998	0.998	0.998	
---	1.0	1.0	1.0	[illegible]	[illegible]	[illegible]	[illegible]	
			0.9	1.007	1.023	1.048	[illegible]	
			0.7	1.002	1.009	1.019	[illegible]	
			0.5	0.999	0.999	0.999	0.999	

[a] The countries' emission limitation and reduction commitments under the KP are expressed with the help of δ_{KP}, the normalized change in emissions between t_1 and t_2: $\delta_{KP} > 0$ — emission reduction; $\delta_{KP} \leq 0$ — emission limitation.

Table 9 continued:

5	0.0	0.0	1.0	[illegible]	[illegible]	[illegible]	[illegible]	Cases 3 and 4 (red-colored area): $p = 0$, $Adj \geq 1$: The fractional factor p which allows that true emission increases can fall above committed level of increases is unconditionally set to 0. No excess emissions, i.e., additional emission increases, are accepted. As a consequence, all countries exhibit identical adjustments Adj.
			0.9	1.000	1.000	1.000	1.000	
			0.7	1.000	1.000	1.000	1.000	
			0.5	1.000	1.000	1.000	1.000	
6	-1.0	1.0	1.0	[illegible]	[illegible]	[illegible]	[illegible]	
			0.9	1.008	1.025	1.049	1.098	
			0.7	1.003	1.010	1.020	1.040	
			0.5	1.000	1.000	1.000	1.000	
	-2.0	2.0	1.0	[illegible]	[illegible]	[illegible]	[illegible]	
			0.9	1.008	1.025	1.049	1.098	
			0.7	1.003	1.010	1.020	1.040	
			0.5	1.000	1.000	1.000	1.000	
---	-3.0	2.9	1.0	[illegible]	[illegible]	[illegible]	[illegible]	
			0.9	1.008	1.025	1.049	1.098	
			0.7	1.003	1.010	1.020	1.040	
			0.5	1.000	1.000	1.000	1.000	
---	-4.0	3.8	1.0	[illegible]	[illegible]	[illegible]	[illegible]	
			0.9	1.008	1.025	1.049	1.098	
			0.7	1.003	1.010	1.020	1.040	
			0.5	1.000	1.000	1.000	1.000	
	-5.0	4.[illegible]	1.0	[illegible]	[illegible]	[illegible]	[illegible]	
			0.9	1.008	1.025	1.049	1.098	
			0.7	1.003	1.010	1.020	1.040	
			0.5	1.000	1.000	1.000	1.000	
...	-6.0	5.7	1.0	[illegible]	[illegible]	[illegible]	[illegible]	
			0.9	1.008	1.025	1.049	1.098	
			0.7	1.003	1.010	1.020	1.040	
			0.5	1.000	1.000	1.000	1.000	
...	-7.0	6.5	1.0	[illegible]	[illegible]	[illegible]	[illegible]	
			0.9	1.008	1.025	1.049	1.098	
			0.7	1.003	1.010	1.020	1.040	
			0.5	1.000	1.000	1.000	1.000	
7	-8.0	7.4	1.0	[illegible]	[illegible]	[illegible]	[illegible]	
			0.9	1.008	1.025	1.049	1.098	
			0.7	1.003	1.010	1.020	1.040	
			0.5	1.000	1.000	1.000	1.000	
	-9.0	8.3	1.0	[illegible]	[illegible]	[illegible]	[illegible]	
			0.9	1.008	1.025	1.049	1.098	
			0.7	1.003	1.010	1.020	1.040	
			0.5	1.000	1.000	1.000	1.000	
8	-10.0	9.1	1.0	[illegible]	[illegible]	[illegible]	[illegible]	
			0.9	1.008	1.025	1.049	1.098	
			0.7	1.003	1.010	1.020	1.040	
			0.5	1.000	1.000	1.000	1.000	

Table 10: Summary overview: The six signal analysis techniques and the characteristics of their numerical responses. To facilitate easy comparison, the techniques are grouped in pairs of two. In the last column, we judge whether or not a technique is in line with the spirit of the KP, mainly determined by the shortfalls which the techniques have to cope with and which are related to the way the KP has been framed and implemented politically (see text). Kyoto (emissions) target (KT).

Technique	Given	Numerical Response	In the Spirit of the KP?[a]
CRU, VT	δ_{KP}	Dissimilarity between countries committed to emission reduction ($\delta_{KP} > 0$) and limitation ($\delta_{KP} \leq 0$) depending on whether more lenient or stricter KTs are introduced: $\delta_{KP} > 0$: Stricter over more lenient KTs are favored $\delta_{KP} \leq 0$: More lenient over stricter KTs are favored	No
Und, GSC #2	δ_{KP}	risk $\alpha \downarrow$ $\Rightarrow$ undershooting Und $\uparrow$ confidence $(1-\alpha) \uparrow$ $\Rightarrow$ adjustment Adj $\uparrow$ for any uncertainty ρ	Yes
	δ_{KP}	uncertainty $\rho \uparrow$ $\Rightarrow$ undershooting Und $\uparrow$ uncertainty $\rho \uparrow$ $\Rightarrow$ adjustment Adj $\uparrow$ for any risk α or confidence $(1-\alpha)$	Yes
	ρ and α (or $1-\alpha$)	$\delta_{KP} \downarrow$ $\Rightarrow$ undershooting Und $\uparrow$ but modified KT $\delta_{mod} \downarrow$ $\delta_{KP} \downarrow$ $\Rightarrow$ adjustment Adj $\uparrow$ or Adj$=$const (but relative to KT)	Und: No GSC #2: Yes[b]
Und&VT, GSC #1	δ_{KP}	as under Und and GSC #2	Yes
	δ_{KP}	as under Und and GSC #2	Yes
	ρ and α (or $1-\alpha$)	$\delta_{KP} \downarrow$ $\Rightarrow$ modified KT δ_{mod} is made 'detectable' (according to Cases 2–4 in Figure 4)[c] $\delta_{KP} \downarrow$ $\Rightarrow$ adjustment Adj $\uparrow$ or Adj$=$const (but relative to KT)	Und&VT: Yes[c] GSC #1: Yes[b]

[a] Under the assumption that accounting GHG emissions bottom-up and top-down do not exhibit biases.

[b] If applied in the undershooting mode.

[c] Statement does not refer to the case of detectability under emission reduction ($\delta_{KP} \geq \delta_{crit} > 0$: Case 1) which has been left unaltered; it behaves like the Und concept from a numerical point of view.