Water Air Soil Pollut: Focus (2007) 7:495–511
DOI 10.1007/s11267-006-9113-7

Prior to Economic Treatment of Emissions and Their Uncertainties Under the Kyoto Protocol: Scientific Uncertainties That Must Be Kept in Mind

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Received: 28 May 2006 / Accepted: 20 December 2006 / Published online: 7 February 2007

Abstract In a step-by-step exercise – beginning at full greenhouse gas accounting (FGA) and ending with the temporal detection of emission changes – we specify the relevant physical scientific constraints on carrying out temporal signal detection under the Kyoto Protocol and identify a number of scientific uncertainties that economic experts must consider before dealing with the economic aspects of emissions and their uncertainties under the Protocol. In addition, we answer one of the crucial questions that economic experts might pose: how credible in scientific terms are tradable emissions permits? Our exercise is meant to provide a preliminary basis for economic experts to carry out useful emissions trading assessments and specify the validity of their assessments from the scientific point of view, that is, in the general context of a FGA-uncertainty-verification framework. Such a basis is currently missing.

Keywords Kyoto protocol · full greenhouse gas accounting · uncertainty · verification · emissions · emission changes · signal detection · emission limitation or reduction commitments · risk of not meeting commitments

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1 Introduction

Full carbon accounting (FCA) or full greenhouse gas accounting (FGA),[1] uncertainty, and verification, in connection with the detection of greenhouse gas (GHG) net flux changes (also termed net flux signals), are crucial issues for the functioning of the Kyoto Protocol (Grassl et al., 2003; Nilsson et al., 2000; Nilsson, Jonas, Obersteiner, & Victor, 2001; Nilsson, Jonas, & Obersteiner, 2002; Nilsson et al., 2007; Schulze, Valentini, & Sanz, 2002; Steffen et al., 1998; Valentini et al., 2000). However, we must observe that these issues are not being concomitantly and rigorously discussed in a holistic context among or between physical scientists and experts from other disciplines (e.g., economics). Physical scientists do not

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[1] FCA refers to a full carbon budget that encompasses and integrates all carbon-related components of all terrestrial ecosystems and is applied continuously in time. The components are typically described by adopting the concept of pools and fluxes to capture their functioning. The reservoirs can be natural or human-impacted and internally or externally linked by the exchange of carbon as well as other matter and energy. Net biome production (NBP) is the critical parameter to consider for long-term (decadal) carbon storage. NBP is only a small fraction of the initial uptake of CO_2 from the atmosphere and can be positive or negative; at equilibrium it is zero (Steffen et al., 1998, p. 1393; Jonas et al., 1999, p. 9; Nilsson et al., 2000, pp. 2, 6–7; Shvidenko & Nilsson, 2003, Section 2). FGA simply extends the definition of FCA to include other relevant GHGs (Nilsson et al., 2007, Section 1). However, a clear agreement on which gases are included is still outstanding.

scrutinize, in a holistic context, the basis that has been set by the political negotiators of the Protocol, nor do they specify the scientific constraints under which the Protocol will operate. There are many consequences of this. To safeguard their carbon trading assessments from an uncertainty-risk point of view, experts from financial institutions might, for example, ask questions that physical scientists cannot answer, such as: how credible in scientific terms are tradable emissions permits? Economics experts typically carry out assessments that are not integrated within a proper physical scientific FGA framework (i.e., they cannot properly specify the validity of their assessments from a physical scientific [verification-related] point of view). Moreover, scientists, for their part, fail to assemble crucial knowledge that will prove useful in improving the Protocol prior to and for its follow-up commitment periods. In this context, we refer to recently completed collaborative work on the preparatory detection of uncertain GHG emission signals under the Kyoto Protocol (Jonas et al., 2004a) that should have been applied before/during negotiation of the Kyoto Protocol and that addresses the question: how well do we need to know what net emissions are if we want to detect a specified emissions signal at a given point in time?

This work advances the emission reporting of Annex I countries under the Protocol, as it takes uncertainty and its consequences into consideration, that is, 1) the risk that a country's true emissions in the commitment year/period are above its true emissions limitation or reduction commitment (i.e., the risk that the country will not meet its commitment); and 2) the detectability of the country's target. The authors' approach can be applied to any net emitter, and in our follow-up work, (Jonas et al. 2004b and 2004c), we demonstrate how evaluation, in terms of risk and detectability, of GHG emission signals can become standard practice. These two qualifiers can be determined and could indeed be accounted for in pricing GHG emissions permits.

We use our preparatory signal detection work as an example in an exercise that identifies step by step beginning at FGA and ending with signal detection the relevant physical scientific constraints and choices that are involved in applying signal detection within an FGA-uncertainty-verification framework. In other words, our signal-detection results can be properly evaluated against a solid physical scientific background. Our primary intention in this exercise is not to undermine the Protocol, which is not placed within such a framework and has also not been subject to preparatory signal detection, but to compensate for the lack of lucidity in the thinking behind the Kyoto Protocol and the conditions under which it will operate, including the consequences that it will have.

Moreover, our signal-detection results are of practical use. Emission signals that are assessable in terms of detectability or statistical significance have a direct bearing on how carbon permits are evaluated economically. Thus, our second intention is to use our work to build a bridge from the physical sciences to economics, that is, to offer properly specified, physical–scientific uncertainty and risk-related information that can be used by economic experts when they are working out the details of emissions trading.

Our paper is structured as follows: in Section 2 we set the stage for working within a consistent FGA-uncertainty-verification framework. In Section 3 we expose the reader to the verification of emissions in the context of bottom–up and top–down accounting. In Section 4 we explain how we merge bottom–up/top–down verification of emissions and temporal signal detection. In Section 5 we present the quantitative results of two fundamentally different preparatory signal-detection techniques and illustrate the far-reaching consequences of dealing with uncertain emission signals. Finally, in Section 6, we summarize the lessons drawn from our step-by-step analysis and establish the background against which we evaluate our signal-detection results.

Our paper is strongly guided by science–theoretical considerations and attempts to present a number of issues in a holistic context, something that has not, to our knowledge, been done elsewhere. While longer discussions of each of the issues is required, we have chosen to keep Sections 2 to 5 short to facilitate reading. However, we insert cross-references, which direct the reader to additional background information where the issues are discussed in greater depth.

2 Setting the Stage for Working within a Consistent FGA-Uncertainty-Verification Framework

In this section we develop an understanding of plausibility, validation, and verification based on our favorite way of categorizing uncertainty (Section 2.1);

we explain accounting versus diagnostic and prognostic modeling in terms of uncertainty (Section 2.2); and we specify the concept as well as the classes that we apply in order to grasp uncertainty quantitatively (Sections 2.3 and 2.4, respectively).

2.1 A Brief Science–Theoretical Discourse: Plausibility, Validation, and Verification

To illustrate the origin of uncertainties, we follow Moss and Schneider (2000; see also Giles, 2002), who categorized uncertainties and espoused the use of a straightforward concept within the Intergovernmental Panel on Climate Change (IPCC). The authors' concept reveals the advantage of fundamental structure: it considers four main categories – corresponding to confidence in the theory, the observations, the model results, and the consensus (understood as soft knowledge) within a field – to which we attach scientific quality labels to indicate whether plausibility, validation, or verification (in ascending order of scientific strictness) can be achieved (see Fig. 1; for comparison see also Vreuls, 2004, Fig. 1; and Gillenwater, Sussman, & Cohen, 2007, Section 2.2). These are specified – in line with science theory (e.g., Lauth & Sareiter, 2002) – according to the definitions used in *Merriam-Webster's Collegiate Dictionary* (Merriam-Webster, 1973 and 1997):

> *Plausibility* (from *plausibilis* = worthy of applause) → plausible: reasonable; appearing worthy of belief <the argument was both powerful and ~>.
> *Validation* (from *validus* = strong) → valid: well grounded or justifiable: being at once relevant and meaningful <a ~ theory>; logically correct (i.e., having a conclusion correctly derived from premises) <a ~ argument>.
> *Verification* (from *verus* = true) → verify: to establish the truth, accuracy, or reality.[2]

In accordance with these definitions, only observations (measurements) that are uncertain per se can be verified; none of the other categories can be verified. Theories and diagnostic models can only be validated or, alternatively, falsified (which is a controversial issue in its own right). Both consensus and prognostic modeling also give rise to uncertainty. However, these two categories can, at best, be judged only as plausible; they can be neither validated nor verified.

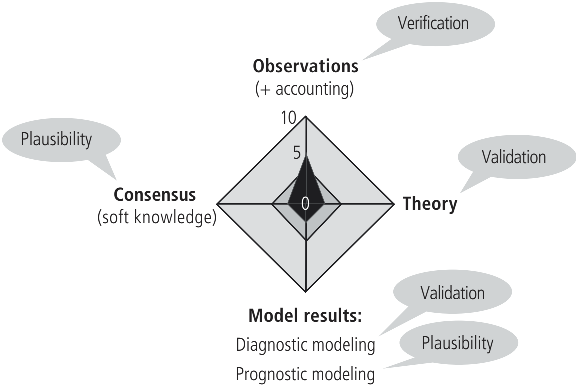

Fig. 1 Scientific quality attached to the four-axis concept of Moss and Schneider (2000, Fig. 5; see also Giles, 2002, p. 477). The figure, designed to trace where uncertainty comes from, is modified to show which scientific quality in terms of plausibility, validation, and verification can be achieved. The authors use a scale of 1–10 to reflect experts' assessments of the amount/quality of, for instance, theory and observations, to support their findings. See text for explanations

Considering that, in the context of the Kyoto Protocol, GHG emissions are not usually measured directly but derived from measurements or statistical surveys, we extend Moss and Schneider's (2000) uncertainty category "observations" to include the (not rigorously specified) category "accounting." This allows us to also consider statistically surveyed data including data (e.g., emissions data) derived with the help of statistically surveyed data (e.g., activity data) in combination with data reported in the literature (e.g., emissions factors).

The terms validation and verification, in particular, are frequently confused and misused. For instance, the IPCC Good Practice Guidelines define verification with the emphasis on GHG emissions inventories (Penman et al., 2000, p. A3.20):

Inventory definition: Verification refers to the collection of activities and procedures that can be followed during the planning and development, or after completion of an inventory that can help to establish its reliability for the intended applications of that inventory. Typically, methods external to the inventory are used to check the truth of the inventory, including comparisons with estimates made by other bodies or with emission and uptake measurements

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[2] In the context of the Kyoto Protocol the term certification is also used, particularly by policy makers. It is specified as in Merriam-Webster (1997):

Certification (from *certus* = certain) → certify: to attest authoritatively: to attest as meeting a standard.

determined from atmospheric concentrations or concentration gradients of these gases.

However, this definition requires discussion, as it is not sufficiently rigorously in line with either science theory or the intended purpose of the Kyoto Protocol, which may be colloquially expressed as, "It's what the atmosphere sees that matters."

According to this definition, verification is a scientific process that aims to establish the reliability of a (bottom–up) inventory. However, similar to "validity," which is a system-internal quality criterion, "reliability" is a measurement-reflexive quality criterion that should not be confused with "verification." Verification is more, as it goes beyond validation or reliability, for example, with the help of an additional experiment that allows the observation to be independently counter-checked. Moreover, in terms of checking the truth of an inventory, this definition allows "comparisons with (bottom–up emission) estimates made by other bodies"[3] to be put on the same level as "emission and uptake measurements determined from atmospheric concentrations or concentration gradients of these gases," which is unacceptable from a science–theoretical point of view, as validation and verification are confused.

2.2 Accounting Versus Diagnostic and Prognostic Modeling

Figure 2 shows the difference in terms of uncertainties between accounting and diagnostic and prognostic modeling. The accounting typically happens with a time step of ≤1 year and may be matched by an emission-generating model during its diagnostic mode. In its prognostic mode, a model can, at best, only reflect a multiyear period that excludes singular stochastic events (although the model may operate with a time step of ≤1 year).[4] The uncertainty associated with accounting U_{Account} reflects our real diagnostic capabilities. It is this uncertainty that underlies both our prior and current accounting and that, under the Kyoto Protocol, we will have to cope with in reality at some time in the future (e.g., commitment year/period). This U_{Account} may decrease with increasing knowledge. (For simplification, we let U_{Account} stay constant in absolute terms over time in Fig. 2.) By way of contrast U_{Model}, the uncertainty of the model, always increases because of the model's decreasing prognostic capabilities with time.[5]

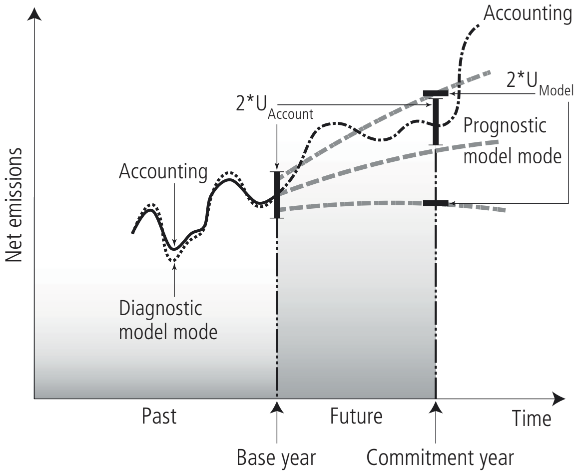

Fig. 2 Illustration of accounting versus diagnostic and prognostic modeling. *U*: uncertainty. Source: Jonas et al., (2004a, Fig. 4)

2.3 Uncertainty Concept

Figure 3 presents the uncertainty concept that we apply to overcome a mismatch of measured (or accounted) mean values, including their uncertainties under validation or verification. The concept acknowledges that there is both available knowledge and lack of knowledge when net carbon emissions are being accounted for. Available knowledge can be hard or soft, while lack of knowledge can be interpreted as the difference between an accepted value and the (unknown) true value that is due to unknown biases. Random errors

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[3] In this context, the terms "third-party verification" or "independent verification" are also used.

[4] To overcome this shortcoming, stochastic events are often exogenously generated in a random fashion and introduced into prognostic models in retrospect, in the hope that their relevance will increase with respect to shorter time scales.

[5] The interrelation between U_{Model} and U_{Account} during the diagnostic mode of the emission-generating model can be made clear with the help of the notion of an ideal model. An ideal model perfectly reflects "reality" (inventory view) during the model's diagnostic mode, that is, U_{Model} is identical to U_{Account}. However, in practice, models are generally not able to reproduce U_{Account} for a number of reasons. An important reason is that, traditionally, model builders focused mainly on grasping mean values. To reflect more a complex reality, the models resolved more-detailed mean values. However, the consideration of uncertainties requires the opposite, that is, that models be simplified, ideally to a level that permits uncertainties to be treated as statistically independent (or as statistically independent as possible). Typically, the realization of a (sufficiently) ideal model is a task in itself.

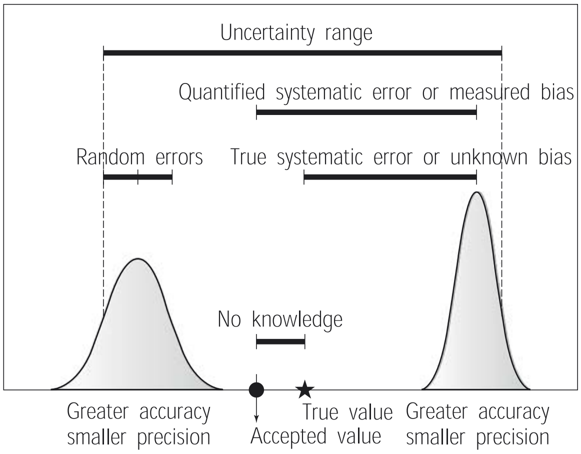

Fig. 3 The applied uncertainty concept to overcome a mismatch of measured (or accounted) mean values, including their uncertainties under validation or verification. Sources: Nilsson et al. (2000, Fig. 12), Jonas et al. (2004a, Fig. 7)

and systematic errors (the latter are also called determinate errors or simply biases, but we prefer quantified systematic errors or measured biases) are typically used to evaluate both hard and soft knowledge in terms of uncertainty. In contrast, lack of knowledge can only be addressed in a way that is necessary but not necessarily sufficient. This is done by defining an uncertainty range that encompasses each of the two measured biases plus each of the two standard deviations representing the random errors of the two depicted measurement sets (for comparison, see also Gillenwater et al., 2007, Section 2.2; and Winiwarter, 2007, Section 2). We note that we have not yet specified at which level of confidence we want to report uncertainty. In contrast to the IPCC (1997a, p.A1.4), which suggests the use of a 95% confidence interval, we favor the 68% confidence level (1 * standard deviation) because, as long as we have to cope with uncertainty ranges as a result of inconsistent or missing knowledge in realizing full carbon accounts, striving for a higher, purely mathematical confidence level cannot be justified physically.[6] For our discussion on bottom–up versus top–down accounting in Section 3 below, we also may want to keep in mind that it is the 68% confidence level that the atmospheric inversion community typically applies.

Table 1 Relative uncertainty classes applied in the full carbon account of Austria

Class	Relative uncertainty (%)
1	0–5
2	5–10
3	10–20
4	20–40
5	>40

Source: Jonas and Nilsson (2001, Section 4.1.3).

2.4 Uncertainty Classes

The derivation of aggregated uncertainties, as in emission inventories, is typically not unambiguous and is even prone to errors. This is why we commonly apply relative uncertainty classes as a good practice measure (see Table 1), as they constitute a robust means of getting an effective grip on (even large) uncertainties. In light of the numerous data limitations and inconsistencies that countries face, the reporting of exact relative uncertainties is not justified.

Our work on the FCA of Austria (Jonas & Nilsson, 2001) shows that experts who share the same data sets typically estimate uncertainty ranges that overlap each other. However, this may no longer be true if the experts use different initial data, process them differently, or apply different systems views (e.g., an intramodular systems view as under partial carbon accounting (PCA) as opposed to an intermodular systems view as under FCA).[7] As a consequence of this robust finding we argue that, contrary to Gillenwater et al., (2007, Section 5), uncertainty estimates of national emission inventories can indeed be used for policy purposes. However, certain rules, particularly those dealing with large uncertainties must be obeyed (see Jonas & Nilsson, 2001, Section 4.3, for details).

Finally, we note that our definition of the relative uncertainty classes as specified in Table 1 is arbitrary and that it attempts to satisfy simple practical consid-

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[6] We thus distinguish between an uncertainty evaluation of Type A and Type B. Type A is the evaluation of uncertainty by the statistical analysis of a series of observations. By way of contrast, Type B is the evaluation of uncertainty by means other than the statistical analysis of series of observations (see Jonas and Nilsson, 2001, Section 4.1.2 for details).

[7] PCA as under the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 1997a, b, c) or the Kyoto Protocol do not form logical and consistent subsets of FCA (which is regarded as the scientifically appropriate approach) (Steffen et al., 1998, p.1394). However, a clear guideline on how to get from PCA to FCA, or vice versa, does not exist.

erations as to how many different intervals one wishes to resolve. The classes reflect our physical and systems analytical thinking behind Austria's full carbon account. For instance, assume that a carbon flux had been specified with a relative uncertainty of 13.7%. We then interpret this value as falling within the respective relative uncertainty class: here 10–20% (class 3).[8] In Section 5.3 below we illustrate how the concept of uncertainty classes is applied in the preparatory detection of emissions signals and the comparison of these signals across (Annex I) countries.

3 Bottom–Up Versus Top–down Accounting: Verification of Emissions

Our starting point is the verification of emissions. In this section we look at carbon emissions, the verification of which is particularly difficult (Nilsson et al., 2001; Bergamaschi, Behrend, & Jol, 2004, pp. 3−5; Nilsson et al., 2007). It requires, following science–theoretical standards, the adoption of an approach that takes an atmospheric view ("what matters is what the atmosphere sees") and is complete – leaving no unverified residues (see Fig. 4). In the context of the Kyoto Protocol, this leads us to the concept of bottom–up/top–down (consistent or dual-constrained) FCA on the country scale,[9] that is, the measurement of all fluxes, including those into and out of the atmosphere (as observed on earth), as well as an atmospheric storage measurement (as observed in the atmosphere), which – to reflect the needs of the Protocol – permits a country's "Kyoto biosphere" to be distinguished from its "non-Kyoto biosphere."[10] This type of FCA would permit verification that is ideal because it would work both ways (bottom–up/top–down). It is, however, unattainable, as there is no atmospheric measurement available (nor likely to be in the immediate future) that can meet this discrimination requirement – not to mention the spatial (country-scale) resolution requirements of the measurement (Jonas et al., 2004a, Section 2.2; Mangino, Finn, & Scheehle, 2005: Sections 1 and 2). As a consequence, PCA – thus, partial greenhouse gas accounting (PGA) – as envisaged under the Kyoto Protocol cannot be verified.

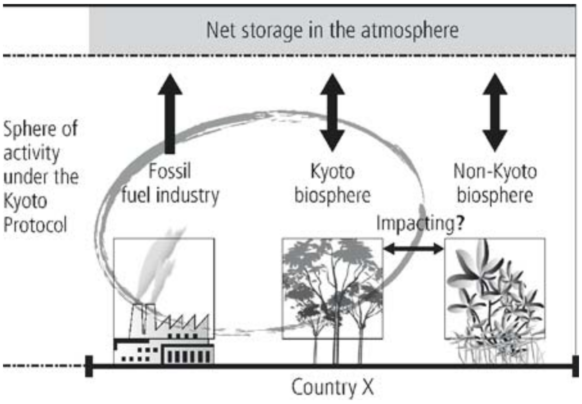

Fig. 4 PCA, as envisaged under the Kyoto Protocol (KP), must be understood as a logical subset of consistent FCA. Consistent FCA on the spatial scales of countries requires the measurement of all fluxes, including those into and out of the atmosphere, and an atmospheric storage measurement, which – to reflect the needs of the Kyoto Protocol – permits a country's "Kyoto biosphere" to be distinguished from its "non-Kyoto biosphere." The anthropogenic sector (simply referred to as fossil fuel [FF] industry) also includes ground-based fluxes between countries (e.g., trade) and carbon stocks other than biospheric stocks. Source: Jonas et al., (2004a, Fig. 5)

4 Bottom–Up/Top–Down Verification of Emissions and Temporal Detection of Emissions Signals

Contrary to the bottom–up/top–down verification of emissions, however, the Kyoto Protocol requires that net emission changes (emission signals) of specified GHG sources and sinks, including those of the "Kyoto biosphere" but excluding those of the "non-Kyoto biosphere," be determined on the spatial scale of countries by the time of commitment, relative to a specified base year.[11] The relevant question then is

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[8] The increasing width of our relative uncertainty classes and our classification of relative uncertainties as unreliable beyond class 3 is in agreement with the IPCC (1997a, p. A1.5), which advises against the application of the law of uncertainty propagation if the relative uncertainties that are combined under this law are greater than 60% (95% confidence level).

[9] The country scale is the principal reporting unit requested for reporting GHG emissions and removals under the Kyoto Protocol (FCCC, 1998, Articles 1 and 7).

[10] Articles 3.3 and 3.4 of the Protocol stipulate that human activities related to land-use change and forestry (LUCF) since 1990 can also be used to meet 2008–2012 commitments (FCCC, 1998). The part of the terrestrial biosphere that is affected by these Kyoto compliant LUCF activities is hereafter referred to as "Kyoto biosphere" and its complement as "non-Kyoto biosphere".

[11] In the figures of our paper, we denote (if not *expressis verbis*) net emissions by x and their changes by Δx, respectively.

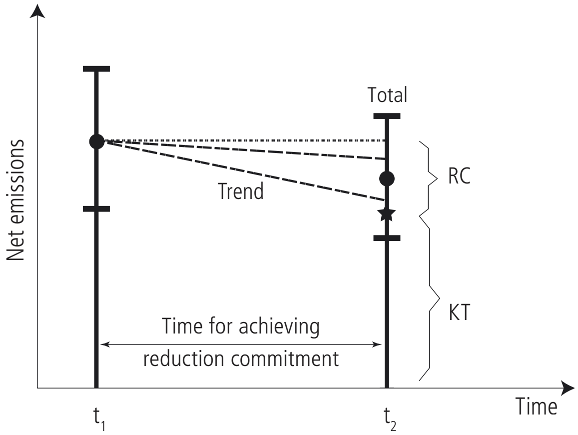

Fig. 5 The IPCC definition of uncertainty with respect to two predefined points in time (*with the respective emissions denoted by* •) based on two different types of uncertainty: total and trend uncertainty. *KT*: Kyoto emission target (*denoted by the star*); *RC*: emission reduction commitment. Source: Jonas et al., (2004a, Fig. 6)

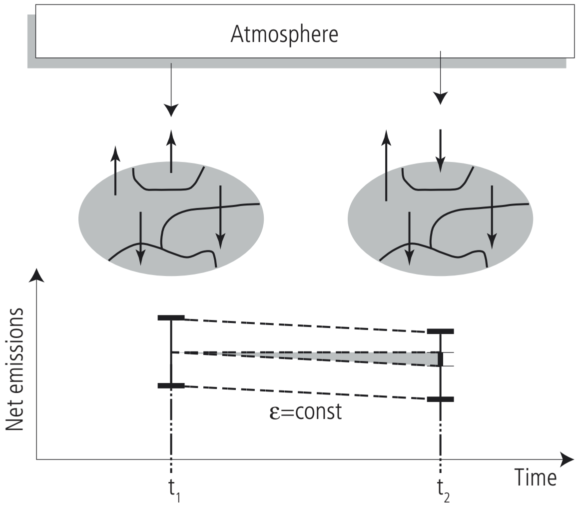

Fig. 6 Dual-constrained verification and signal detection. Source: Jonas et al., (2004a, Box 1, modified). Assume that we were able to repeatedly carry out dual-constrained FCA for a given terrestrial region at times t_1 and t_2 (appropriately averaged in space and time). Assume further that our bottom–up full carbon account would be more highly resolved than our top–down full carbon account. Nevertheless, both the bottom–up and the top–down full carbon account would exhibit "reasonable" agreement, meaning that their mean atmospheric net fluxes would be sufficiently close and could be characterized by a combined uncertainty, which would be "acceptable." However, although we would work bottom–up/top–down (i.e., apply dual-constrained FCA), we could still encounter potential difficulties, as the graph at the bottom of the figure shows. Here, the change in the net emissions at t_2 disappears within the constant-width uncertainty band. What must be kept in mind is that our bottom–up/top–down FCA technique refers to net atmospheric emissions and their uncertainties, but we need to go beyond the verification of emissions when explicitly considering time and assessing when the emission signal is outstripping uncertainty. To handle such situations, we have to additionally utilize signal detection techniques

whether these emission signals outstrip uncertainty and can be "verified" (correctly: detected).

The IPCC (to which the Kyoto Protocol appeals)[12] defines uncertainty with respect to two predefined points in time: the base year and the commitment year/period (Penman et al., 2000, Chapter 6; 2003, Chapter 5; Watson et al., 2000, Section 2.3.7). Figure 5 reflects this concept based on two different types of uncertainty, total and trend uncertainty.[13] Notwithstanding, we argue here that – if we ever want to place signal detection meaningfully into a bottom–up/top–down verification context – it is the total uncertainty in the commitment year/period that matters, as long as we are still searching for the accurate mean emission values (see Fig. 6).[14] Hence, merging bottom–up/top–down verification of emissions and temporal detection of emission signals is the scientific challenge. It is important to realize that this challenge can be addressed successfully only if signal detection acknowledges total uncertainty. Trend uncertainty is inappropriate because it provides only second-order information (related to the change of a difference, where the difference is given by the net flux itself and the change is given by the change in the net flux over time); that is, trend uncertainty can be used to investigate how certain or uncertain an emission trend is, but it provides no information as to whether or not a realized change in net emissions is detectable.

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[12] See FCCC (1998, Article 5; 2002, pp. 3−13; 2004, pp. 31−32).

[13] In the context of the Kyoto Protocol, the total (or level) uncertainty reflects our real diagnostic (accounting) capabilities, that is, the uncertainty that underlies our past (base year) accounting 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).

[14] In the commitment year/period t_2 we ask, in accordance with the concept of bottom–up/top–down verification, for the total uncertainty at that point in time, not whether or not the total uncertainty at t_2 can be decreased, for example, on the basis of correlative techniques (i.e., our emission and uncertainty knowledge at t_1, the base year).

However, as discussed in Section 5.1 below, the knowledge of total uncertainty at only two points in time without a consideration of the dynamics of the emission signal can lead to interpretational difficulties as to whether or not the emission signal is detectable. (We circumvent these difficulties in Section 5.3.)

5 Temporal Detection of Emission Signals

This section focuses on the temporal detection of emission signals, which we assume to be embedded, as discussed above, in a bottom–up/top–down verification context. In Section 5.1 we explain in greater detail what we understand under a detectable emission signal vis-à-vis one that is statistically significant. Sections 5.2 and 5.3 serve to illustrate the far-reaching consequences of dealing with uncertain emission signals.

5.1 Detectability Versus Statistical Significance

Figure 7 illustrates that the notion of statistical significance is insufficient for addressing compliance under the Kyoto Protocol, as the statistical significance of an emission signal does not imply its detectability. In other words, the IPCC falls short in providing adequate support for the Protocol, as the problem of detecting emission signals – and hence, the issue of the Protocol's effectiveness (Gupta, Olsthoorn, & Rotenberg, 2003, Section 3) – still goes unresolved.[15] We address this problem with the help of the verification time (VT) concept; this perceives signal detection in the same way as climate change researchers traditionally have, that is, as a "signal-in-noise" problem (Houghton et al., 2001, Chapter 12).[16] This concept makes use of the dynamics of an emission signal and compares it with the uncertainty that underlies the emissions, not the emission signal (i.e., making the step from a to b in Fig. 8). Only a comparison of this type permits signal detection to be addressed and the question to be asked: when does an emission signal outstrip uncertainty? Considering emissions or emission changes individually within their respective uncertainty bands (i.e., staying within Fig. 8a or b, respectively) does not permit this to be done.

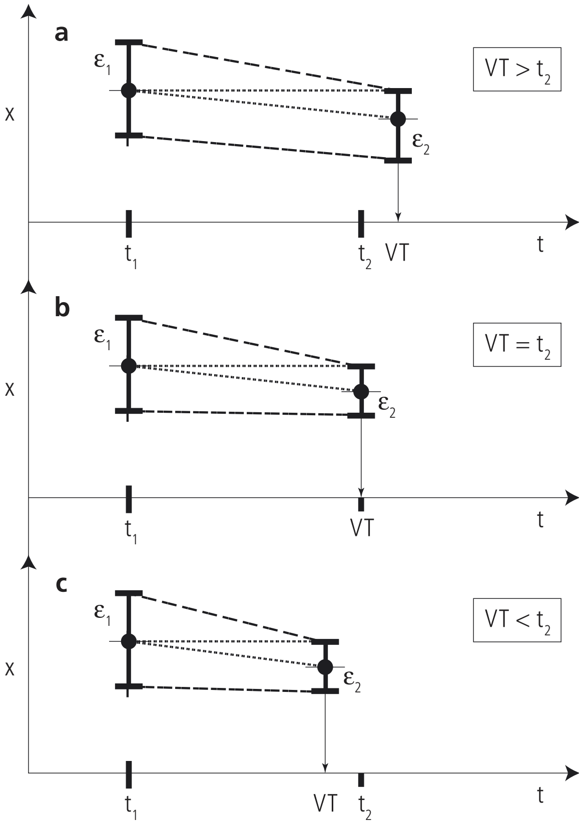

Fig. 7 Illustration of the VT concept. Assume a statistically significant (absolute) change in emissions, which outstrips uncertainty at **a** VT>t_2; **b** VT=t_2; and **c** VT<t_2. (See caption to Fig. 8 for an explanation of the symbols.) Source: Jonas et al., (2004a, Fig. 10, modified)

5.2 No Credibility Without Uncertainty

Uncertainty in the accounting matters from both a systems-analytical point of view (see Fig. 9) and an economic point of view (see Fig. 10). In Fig. 9 we study the superposition of GHG systems exhibiting different dynamics but identical effective emission signals. The figure illustrates and compares the linear and nonlinear behavior of two (here) national GHG systems in terms of their VTs. The two systems are a national anthropogenic system (simply referred to as

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[15] Gupta et al., (2003) argue differently but come to the same conclusion.

[16] The term "verification time" was first used by Jonas et al., (1999) and has been used by other authors since then. Actually, 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.

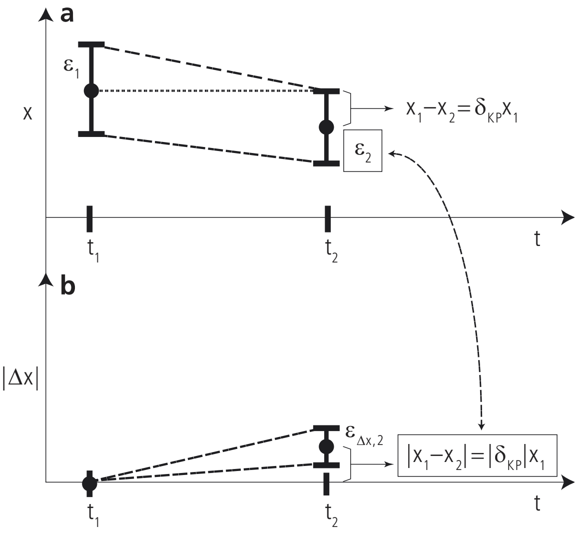

Fig. 8 **a** Emissions x_i and **b** (absolute) emission signal $|\Delta x_i|$ at t_i, together with their respective uncertainties ε_i and $\varepsilon_{\Delta x,i}$ (i=1, 2). δ_{KP} denotes the normalized emissions change committed to by a country under the Kyoto Protocol (see also Section 5.3). To address the question of when the emission signal outstrips uncertainty, the emission signal is compared with the uncertainty that underlies the emissions, not the emission signal (see dashed arrow between lower and upper figure). Source: Jonas et al., (2004a, Fig. A1, modified)

fossil fuel or FF system) and a national FF-plus-LUCF system. This comparison shows (see also caption to Fig. 9) that the consideration of uncertainty indeed makes a big difference in terms of the detectability of emission signals and their qualitative interpretation, even if the effective emission signals of the two countries are identical.

The same is true from an economic point of view (e.g., for emissions trading). Without uncertainty, sellers of equal amounts of carbon (or their equivalents) cannot be distinguished (Fig. 10, top), that is, they cannot be specified in terms of credibility. Figure 10 (bottom) shows that awkward cases are indeed possible, for example, when a country complying with the Kyoto Protocol performs worse than a country not complying with the Protocol. (To handle such cases requires the consideration of risk, which we do in Section 5.3.) Clearly, emissions trading can be defined in such a way that it functions according to rules that ignore uncertainties altogether, including physical scientific uncertainties. However, we doubt that this strategy will be crowned with success in the long term, especially if such rules lead to a misconstruction of compliance in the end and the physical scientific community thus objects to them. Hence, we argue that the success of an emissions market will crucially depend on its credibility and, thus, on the reporting of physical scientific uncertainties.

5.3 Different Techniques–Different Endings

In this section we become quantitative. We focus on the preparatory detection of emission signals, which should have been applied prior to/during the negotiation of the Kyoto Protocol. Preparatory detection allows useful information to be generated in advance regarding the possible magnitude of uncertainties due to 1) the level of confidence of the emission signal; 2) the signal one wishes to detect; and 3) the risk one is willing to tolerate in not meeting an agreed emission limitation or reduction commitment. Preparatory signal detection aims to assess emission signals in a preparatory manner, that is, at two predefined points in time: t_1 in the past/present (typically the base year) when emissions are known and t_2 in the future (typically the commitment year/period) when emissions are supposed to meet an agreed target.[17] It is correct to say that preparatory signal detection is currently more advanced in comparison with midway signal detection and signal detection in retrospect (e.g., Jonas, Nilsson, Obersteiner, Gluck, & Ermoliev, 1999; Gusti & Jęda, 2002; Dachuk, 2003; Nahorski & Jęda, 2007), Midway signal detection is carried out at some point in time between the base year and commitment year/period and considers a signal's path realized to date vis-à-vis a possible path toward the agreed emission target. Signal detection in retrospect is carried out at the end of the commitment year/period and considers how an emission signal has evolved in reality between the base year and commitment year/period.

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[17] Different combinations of time points are referred to in the context of the Kyoto Protocol to account for GHG emissions and removals by sink and source categories on the level of countries. Without restricting generality, we use t_1 and t_2. They may refer to any two points on the time scale T_0=1990 (or another base year), ..., T_{15}=2005, ..., T_{18}=2008, ..., T_{20}=2010, ..., T_{22}=2012. The year 2010 is used as commitment year if t_2 refers to the temporal average in net emissions over the commitment period 2008–2012.

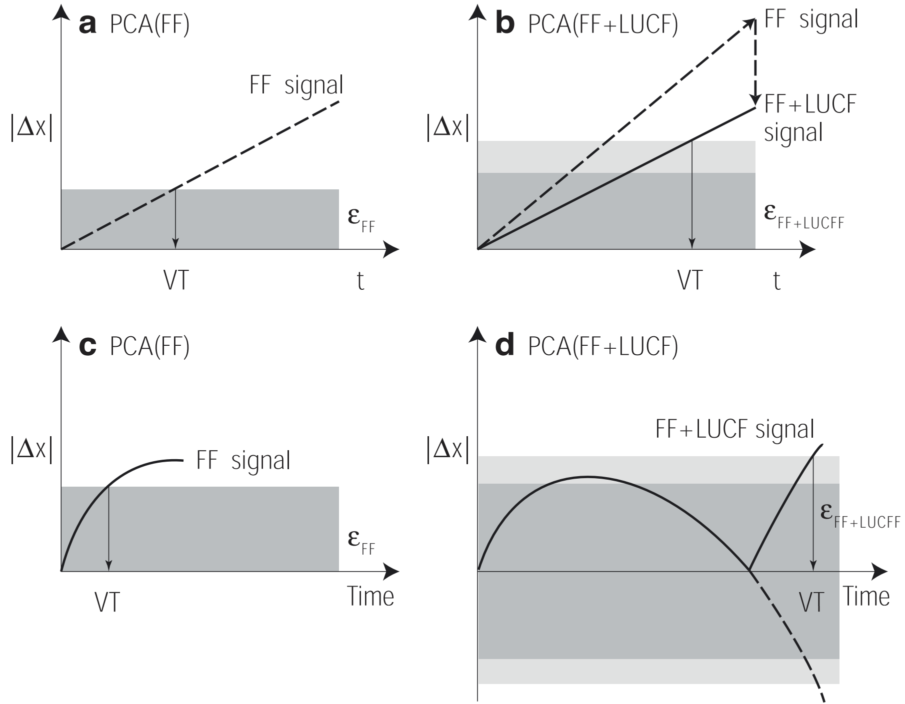

Fig. 9 Illustration of the linear (**a**, **b**) and nonlinear (**c**, **d**) behavior of VT with the help of the two partially accounted, Kyoto-eligible systems: PCA(FF) and PCA(FF+LUCF). **a**, **b** Here, the two systems exhibit identical effective emission signals but different uncertainties ($\varepsilon_{\mathrm{FF}}$ and $\varepsilon_{\mathrm{FF+LUCF}}$, respectively, with $\varepsilon_{\mathrm{FF}} < \varepsilon_{\mathrm{FF+LUCF}}$) and thus different VTs. **c**, **d** Here, the two systems also exhibit identical effective emission signals, but now the FF+LUCF signal exhibits a jumpy VT behavior as a result of combining a nonlinear FF signal and a LUCF signal with slow dynamics (as in **b**). (For a better overview, the LUCF signal has been omitted in **d**.) The linear and nonlinear behavior of the VT can be easily checked by slowly increasing the width of the *light-grey bar* ($\varepsilon_{\mathrm{LUCF}}$), beginning from zero. Sources: Jonas and Nilsson (2001, Figs. 8, 12); see also Gusti and Jęda (2002, Fig. 17)

Our experience to date shows that there is no ideal preparatory signal detection technique; each has its pros and cons. We demonstrate this with the help of the Undershooting (Und) concept and the combined Undershooting and Verification Time (Und and VT) concept, which have been compared in detail by Jonas et al. (2004a, Sections 3.3 and 3.4). The Und concept was first described by Nahorski et al. (2003), and a more advanced version is now presented by Nahorski, Horabik and Jonas (2007), which these authors also use for their "downstream research" on the performance of carbon markets in the presence of uncertainty (see also Horabik & Nahorski, 2004).

The starting point of both the Und and the Und and VT concepts is that Annex I countries comply with their emission limitation or reduction commitments under the Kyoto Protocol.[18] They also employ the same (first-order) assumptions that are in accordance with the preparatory signal detection concept and are fully sufficient for the purpose of this paper, viz.:

(1) Uncertainties at t_1 (base year) and t_2 (commitment year/period) are given in the form of

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[18] For data availability reasons and because of the excellent possibility of intercountry comparisons, the Protocol's Annex I countries are used as net emitters. Their emissions/removals due to LUCF are excluded as the reporting of their uncertainties is only just becoming standard practice. The same conditions have been applied by Jonas et al., (2004b and 2004c) in their intercountry comparison of the EU member states under the EU burden sharing in compliance with the Kyoto Protocol. As a consequence of excluding emissions/removals due to land use change and forestry, our exercise here is restricted to the preparatory detection of uncertain flux signals (which we call emission signals), that is, the preparatory detection of stock-change signals is excluded. In Jonas et al., (2004a, Appendices A and C) the authors build a bridge to "stock changes" and explain how the latter can be considered.

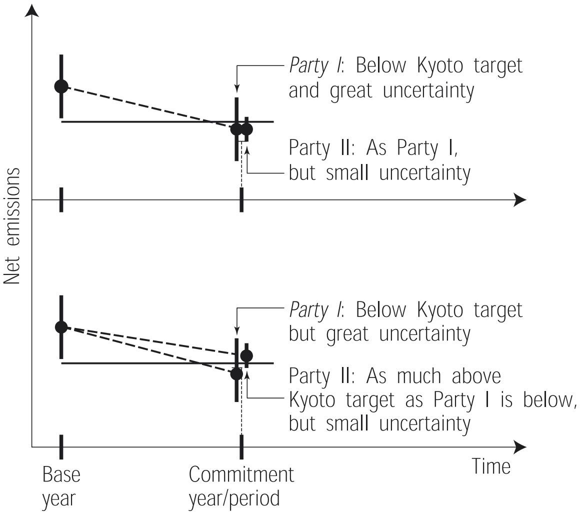

Fig. 10 Emissions trading: which country (or, more generally, "Party" in the terminology of the Kyoto Protocol) is more credible? This graphical representation illustrating the importance of uncertainty in the context of the Kyoto Protocol here addresses the crucial question of credibility while presupposing detectable net emission changes. The uncertainty intervals of both Party I and Party II encompass the same Kyoto target, but which Party is more credible in terms of emissions trading? *Top*: Both parties undershoot the Kyoto target, but Party I exhibits a greater uncertainty interval than Party II. *Bottom*: Party I exhibits a greater uncertainty interval, the mean of which undershoots the Kyoto target, while Party II exhibits a smaller uncertainty interval, the mean of which, however, does not comply with the Kyoto target

intervals that take into account that a difference might exist between the true but unknown net emissions $(x_{t,i})$ and their best estimates (x_i) (i= 1, 2). These differences are captured with the help of ε_i (i=1, 2):

$$\left|x_{t,1} - x_1\right| \leq \varepsilon_1, \tag{1}$$

$$\left|x_{t,2} - x_2\right| \leq \varepsilon_2. \tag{2}$$

(2) The relative uncertainty (ρ) of a country's net emissions is symmetrical and does not change over time (i.e., ρ=const).

The question posed in connection with the Und concept is (see Fig. 11): by how much must countries undershoot their Kyoto targets to decrease the risk (α) that their true emissions in the commitment year/period do not undershoot (i.e., overshoot) their true emission limitation or reduction commitments? The answer is given by:

$$\begin{aligned} x_{t,2} &\geq (1-\delta_{\mathrm{KP}})x_{t,1} \Leftrightarrow \\ \frac{x_2}{x_1} &\leq (1-\delta_{\mathrm{KP}})\frac{1-(1-2\alpha)\rho}{1+(1-2\alpha)\rho} \\ &\approx 1-\{\delta_{\mathrm{KP}}+2(1-2\alpha)(1-\delta_{\mathrm{KP}})\rho\}, \end{aligned} \tag{3a, b}$$

where δ_{KP} is the normalized emissions change committed by a country under the Protocol; the undershooting U is specified by:

$$\begin{aligned} U &= 2(1-\delta_{\mathrm{KP}})\frac{(1-2\alpha)\rho}{1+(1-2\alpha)\rho} \\ &\approx 2(1-2\alpha)(1-\delta_{\mathrm{KP}})\rho\,; \end{aligned} \tag{4a, b}$$

and the country's modified (mod) emission reduction target δ_{mod} is defined by:[19]

$$\delta_{\mathrm{mod}} = \delta_{\mathrm{KP}} + U. \tag{5}$$

The question posed in connection with the Und and VT concept is similar but additionally considers the detectability of an emission signal (see Fig. 12): by how much must countries undershoot their Kyoto-compatible, but detectable, targets to decrease the risk (α) that their true emissions in the commitment year/period do not undershoot (i.e., overshoot) their true emission limitation or reduction commitments? Here, the answer for the case where a country's critical (crit) or detectable emission reduction target δ_{crit} is greater than its Kyoto reduction target δ_{KP} (the case $\delta_{\mathrm{crit}} \leq \delta_{\mathrm{KP}}$ is covered by the Und concept above) is given by:

$$\begin{aligned} x_{t,2} &\geq (1-\delta_{\mathrm{crit}})x_{t,1} \Leftrightarrow \\ \frac{x_2}{x_1} &\leq (1-\delta_{\mathrm{crit}})\frac{1}{1+(1-2\alpha)\rho} \\ &\approx 1-\left\{\delta_{\mathrm{KP}}+U_{\mathrm{Gap}}+(1-2\alpha)(1-\delta_{\mathrm{crit}})\rho\right\}, \end{aligned} \tag{6a, b}$$

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[19] Here, we use the Und concept in its most simple form, which does not consider any correlation between the uncertainty in the base year (ε_1) and the uncertainty in the commitment year/period (ε_2). This is a consequence of making use of the triangle inequality, which does not permit correlations to be considered. In contrast, Nahorski et al., (2007, Section 8) make use of the UND concept by applying a stochastic approach, which allows correlation to be taken into account.

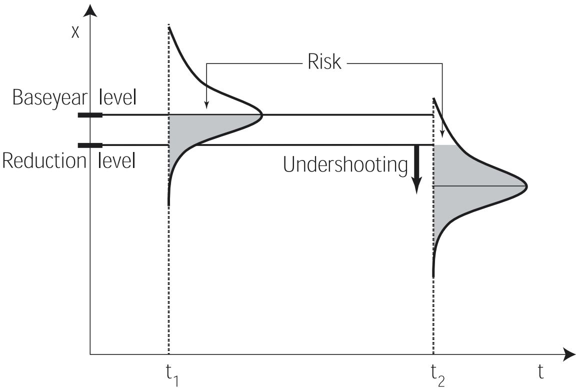

Fig. 11 Preparatory signal detection: Undershooting (Und) concept here illustrated for the case of emission reduction with the help of continuous probability distribution functions. The question posed is: how much must countries undershoot their Kyoto targets to decrease the risk of their true emissions in the commitment year/period not undershooting (i.e., overshooting) their true emission limitation or reduction commitments?

where δ_{crit}, U and U_{Gap} are specified by:

$$\delta_{\text{crit}} = \frac{\rho}{1+\rho}; \tag{7}$$

$$\begin{aligned} U &= U_{\text{Gap}} + (1-\delta_{\text{crit}})\frac{(1-2\alpha)\rho}{1+(1-2\alpha)\rho} \\ &\approx U_{\text{Gap}} + (1-2\alpha)(1-\delta_{\text{crit}})\rho; \end{aligned} \tag{8a, b}$$

and

$$U_{\text{Gap}} = \delta_{\text{crit}} - \delta_{\text{KP}}; \tag{9}$$

while the country's modified emission reduction target δ_{mod} is still given by Eq. 5.[20]

Table 2 refers to the Und concept and Table 3 to the Und and VT concept. They list the modified emission reduction targets δ_{mod} for Annex I countries committed to emission reduction, for which the “$x_{t,2}$-greater-than-$(1-\delta_{\text{KP}})x_{t,1}$“ or “$x_{t,2}$-greater-than-$(1-\delta_{\text{crit}})x_{t,1}$” risk ($\alpha$) is specified to take on the values 0, 0.1, 0.3, and 0.5. The tables should be read as follows (compare, for example, Table 2): If a country of group 1 complies with its emission reduction commitment, that is, $x_2(=1-\delta_{\text{KP}})x_1$, the risk that its true but unknown emissions $x_{t,2}$ are actually equal to or greater than its true but unknown target $(1-\delta_{\text{KP}})x_{t,1}$ is 50%. Undershooting decreases this risk. For instance, an Annex I country has committed itself to reducing its net emissions by 8%. Reporting with a relative uncertainty of ρ=7.5% (median of uncertainty class 2), the country has to reduce its emissions by 20.8% to decrease the risk from 50 to 0%.

Table 2 shows that the Und concept is difficult to justify politically in the context of the Kyoto Protocol. Under the Protocol, nonuniform emission reduction commitments (see δ_{KP} values in the third column) were determined “off the cuff,” meaning that they were derived via horse trading and not as a result of rigorous scientific considerations. The outcome is discouraging. Varying δ_{KP} while keeping the relative uncertainty (ρ) and the risk (α) constant shows that Annex I countries complying with a smaller δ_{KP} are better-off than countries that must comply with a greater δ_{KP}. (See, for example, the bolded δ_{mod} values in the column for ρ=7.5%, which refer to the same risk α=0.3 and decrease with decreasing δ_{KP}.) Such a situation is not in line with the spirit of the Kyoto Protocol.

Table 3, on the other hand, reveals crucial difficulties in terms of realizing the Und and VT concept. This concept requires the Protocol's emission reduction targets for nondetectability to be corrected through the introduction of an initial or obligatory undershooting (U_{Gap}) so that the countries' emission signals become detectable (i.e., meet the maximal allowable VT) before the countries are permitted to make economic use of their excess emission reductions. (See, for example, group 1 countries; that is, the line for δ_{KP}=8%: the δ_{mod} value for ρ=15% (median of uncertainty class 3) and α=0.5 is $\delta_{\text{mod}} = \delta_{\text{KP}} +$

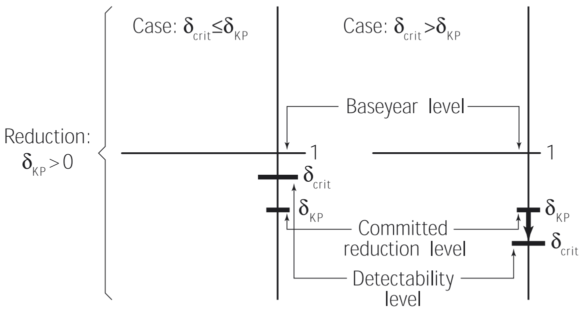

Fig. 12 Preparatory signal detection: Combined Undershooting and Verification Time (Und&VT) concept here for the case of emission reduction. Here the relevant question, though similar to the one posed under the Und concept, additionally considers the detectability of emission signals

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[20] The Und and VT concept only considers the uncertainty in the commitment year/period (ε_2).

Table 2 The Und concept (Eq. 5 in combination with Eq. 4a) applied to Annex I countries committed to emission reduction ($\delta_{KP}>0$)

Country Group	Max. Allowable VT$^{a)}$ t_2-t_1 yr	KP Commit. δ_{KP} %	Modified Emission Limitation or Reduction Targets δ_{mod} in % for ρ =			
			2.5 %	7.5 %	15 %	30 %
			and			
			$\alpha=0.0$ $\alpha=0.1$ $\alpha=0.3$ $\alpha=0.5$	$\alpha=0.0$ $\alpha=0.1$ $\alpha=0.3$ $\alpha=0.5$	$\alpha=0.0$ $\alpha=0.1$ $\alpha=0.3$ $\alpha=0.5$	$\alpha=0.0$ $\alpha=0.1$ $\alpha=0.3$ $\alpha=0.5$
1a **1b** **1c** **1d**	20 22 21 24	8.0	12.5 11.6 9.8 8.0	20.8 18.4 13.4 8.0	32.0 27.7 **18.4** 8.0	50.5 43.6 27.7 8.0
2	20	7.0	11.5 10.6 8.8 7.0	20.0 17.5 12.4 7.0	31.3 26.9 **17.5** 7.0	49.9 43.0 26.9 7.0
3a **3b** **3c**	20 24 22	6.0	10.6 9.7 7.9 6.0	19.1 16.6 11.5 6.0	30.5 26.1 **16.6** 6.0	49.4 42.4 26.1 6.0
4	20	5.0	9.6 8.7 6.9 5.0	18.3 15.8 10.5 5.0	29.8 25.4 **15.8** 5.0	48.8 41.8 25.4 5.0
---	---	4.0	8.7 7.8 5.9 4.0	17.4 14.9 9.6 4.0	29.0 24.6 **14.9** 4.0	48.3 41.2 24.6 4.0
---	---	3.0	7.7 6.8 4.9 3.0	16.5 14.0 8.7 3.0	28.3 23.8 **14.0** 3.0	47.8 40.5 23.8 3.0
---	---	2.0	6.8 5.8 3.9 2.0	15.7 13.1 7.7 2.0	27.6 23.0 **13.1** 2.0	47.2 39.9 23.0 2.0
---	---	1.0	5.8 4.9 3.0 1.0	14.8 12.2 6.8 1.0	26.8 22.2 **12.2** 1.0	46.7 39.3 22.2 1.0

The table lists the modified reduction targets (δ_{mod}) for these countries, for which the "$x_{t,2}$-greater-than-$(1-\delta_{KP})x_{t,1}$" risk (α) is specified to take on the values 0, 0.1, 0.3, and 0.5. The maximal allowable VTs (equal to commitment year/period minus base year) are also reported for these countries. Source: Jonas et al., (2004a, Table B1), modified.

[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, respectively.

The country groups referred to in Table 2 are: 1a: AT, BE, CH, CZ, DE, DK, EC, EE, ES, FI, FR, GR, IE, IT, LI, LT, LU, LV, MC, NL, PT, SE, SK, UK; 1b: BG; 1c: RO; 1d: SI; 2: US; 3a: CA, JP; 3b: HU; 3c: PL; 4: HR.

For ISO country codes, see http://www.iso.ch/iso/en/prods-services/iso3166ma/02iso-3166-code-lists/list-en1.html

$U_{Gap}=13\%$ (U=U_{Gap}) that is, the initial or 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 I countries, as it forces them to strive for detectability (i.e., to make an initial investment before they can profit from their economic actions). Notwithstanding, those who strictly oppose renegotiating the Protocol's emission-limitation or reduction targets must realize that their attitude is very dangerous as the countries' "detectability" (i.e., the "$x_{t,2}$-greater-than-$(1-\delta_{KP})x_{t,1}$“ risk or "$x_{t,2}$-greater -than-$(1-\delta_{crit})x_{t,1}$“ risk of their emission signals) can be grasped and thus priced – although the countries' true net emissions are unknown!

Table 3 The Und and VT concept (Eq. 5 in combination with Eq. 8a) applied to Annex I countries committed to emission reduction ($\delta_{KP}>0$)

Country Group	Max. Allow. VT$^{a)}$	KP Com. δ_{KP}	Crit. Targ. δ_{crit}	Modified Emission Limitation or Reduction Target δ_{mod} in % for ρ =			
	$t_2 - t_1$ yr	%	%	2.5 %	7.5 %	15 %	30 %
			for ρ =	and			
			2.5% 7.5% 15% 30%	a = 0.0 a = 0.1 a = 0.3 a = 0.5	a = 0.0 a = 0.1 a = 0.3 a = 0.5	a = 0.0 a = 0.1 a = 0.3 a = 0.5	a = 0.0 a = 0.1 a = 0.3 a = 0.5
1a	20	8.0	2.4	10.2	14.4	24.4	40.8
1b	22		7.0	9.8	13.2	22.4	38.0
1c	21		13.0	8.9	10.7	18.0	31.3
1d	24		23.1	8.0	8.0	13.0	23.1
2	**20**	7.0	2.4	9.3	13.5	24.4	40.8
			7.0	8.8	12.3	22.4	38.0
			13.0	7.9	9.7	18.0	31.3
			23.1	7.0	7.0	13.0	23.1
3a	20	6.0	2.4	8.3	13.5	24.4	40.8
3b	24		7.0	7.8	12.2	22.4	38.0
			13.0	6.9	9.7	18.0	31.3
3c	22		23.1	6.0	7.0	13.0	23.1
4	20	5.0	2.4	7.3	13.5	24.4	40.8
			7.0	6.9	12.2	22.4	38.0
			13.0	5.9	9.7	18.0	31.3
			23.1	5.0	7.0	13.0	23.1
---	---	4.0	2.4	6.3	13.5	24.4	40.8
			7.0	5.9	12.2	22.4	38.0
			13.0	5.0	9.7	18.0	31.3
			23.1	4.0	7.0	13.0	23.1
---	---	3.0	2.4	5.4	13.5	24.4	40.8
			7.0	4.9	12.2	22.4	38.0
			13.0	4.0	9.7	18.0	31.3
			23.1	3.0	7.0	13.0	23.1
---	---	2.0	2.4	4.8	13.5	24.4	40.8
			7.0	4.4	12.2	22.4	38.0
			13.0	3.4	9.7	18.0	31.3
			23.1	2.4	7.0	13.0	23.1
---	---	1.0	2.4	4.8	13.5	24.4	40.8
			7.0	4.4	12.2	22.4	38.0
			13.0	3.4	9.7	18.0	31.3
			23.1	2.4	7.0	13.0	23.1

The table lists the modified reduction targets (δ_{mod}) for these countries, for which the "$x_{t,2}$-greater-than-$(1-\delta_{crit})x_{t,1}$" risk (α) is specified to take on the values 0, 0.1, 0.3, and 0.5 ($\delta_{crit}>\delta_{KP}$). Light-grey shaded fields: $\delta_{crit}\le\delta_{KP}$. Here, the modified reduction targets (δ_{mod}) are directly taken from Table 2. The maximal allowable VTs (equal to commitment year/period minus base year) as well as the critical (detectable) emission reduction targets (δ_{crit}) are also reported for these countries. Source: Jonas et al., (2004a, Table D4, modified).

[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, respectively.

The country groups referred to in Table 3 are: 1a: AT, BE, CH, CZ, DE, DK, EC, EE, ES, FI, FR, GR, IE, IT, LI, LT, LU, LV, MC, NL, PT, SE, SK, UK; 1b: BG; 1c: RO; 1d: SI; 2: US; 3a: CA, JP; 3b: HU; 3c: PL; 4: HR.

For ISO country codes, see http://www.iso.ch/iso/en/prods-services/iso3166ma/02iso-3166-code-lists/list-en1.html

6 Conclusions

After having set the stage (in Section 2) for working within a consistent FGA-uncertainty-verification framework, we have (in Sections 3−5): 1) specified step by step the relevant conditions for carrying out temporal signal detection, here restricted to preparatory signal detection, under the Kyoto Protocol; and 2) answered a crucial question that economic experts might pose, namely, how credible in scientific terms are tradable emissions permits? Our exercise is meant to provide a preliminary basis for economic experts to carry out useful emissions trading assessments and specify the validity of their assessments from a physical scientific point of view, that is, in the general context of the aforementioned framework. Such a basis is missing.

We draw the following conclusions from our step-by-step analysis:

Section 3	The Kyoto Protocol cannot be verified bottom–up/top–down if the biosphere is split into a "Kyoto biosphere" and a "non-Kyoto biosphere." Note, however, that this conclusion does not necessarily compel FCA under the Kyoto Protocol.
Section 4	The temporal detection of emission changes cannot be placed meaningfully in a bottom–up/top–down verification context if signal detection does not acknowledge total uncertainty.
Section 5.1	The concept of statistical significance is insufficient to address compliance under the Kyoto Protocol, as the statistical significance of an emission signal does not imply its detectability.
Section 5.2	Without uncertainty, the issue of scientific credibility under the Kyoto Protocol cannot be adequately addressed, which, in turn, will be crucial for the success of the emissions market.
Section 5.3	Signal detection techniques differ; each has its pros and cons. A discussion on which technique to select has not even started. Those who strictly oppose renegotiating the Protocol's emission-limitation or reduction targets must realize that their attitude is very dangerous, as the risk that countries' true emissions in the commitment year/period may be above the true equivalents of their committed targets can be grasped, as can the detectability; thus a monetary price can be put on them – although the countries' true net emissions are unknown! Not evaluating the countries' emission signals in terms of detectability could risk diminishing the success of the emissions markets.

It is against this background that we evaluate our signal detection results.

The way the Kyoto Protocol is framed leaves us with the awkward problem of choosing between a number of bad or undesirable alternatives in applying preparatory signal detection: simply ignoring uncertainty knowing that emission markets will then lack scientific credibility versus giving preference to one detection technique over another knowing that none is ideal. The Und concept puts countries that comply with a great δ_{KP} at a disadvantage, while the Und and VT concept requires that the countries' emission signals become detectable before the countries are permitted to make economic use of their excess emission reductions. This problem started with the Kyoto policy process running ahead of science; and we must expect that it will stay with us and not simply vanish (i.e., it will also be present under midway signal detection and signal detection in retrospect). To tackle this problem, it is advisable to initially base discussions on whether or not uncertainty should be taken into consideration at all. As the comparison of Table 2 and Table 3 shows, both the Und and Und and VT concepts require considerable undershooting (the Und and VT concept slightly less than the Und concept) if we want to keep the risk low ($\alpha \approx 0.1$) of countries' true emissions in the commitment year/period being above their true Kyoto targets or their Kyoto-compatible, but detectable, targets.[21]

We recall that our primary intention in using this exercise is not to undermine the Kyoto Protocol but to increase the lucidity that is lacking in the thinking behind it and the conditions under which it will operate. From our analysis it becomes clear that great efforts are still required to properly place the Kyoto Protocol in a consistent FGA-uncertainty-verification framework. Making this effort is necessary if we want to reduce the risk of the Protocol failing in the future.

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