24/2003

Raport Badawczy
Research Report

RB/20/2003

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Warszawa 2003

First Country Studies Confirm System-Analytical Doubts of the Kyoto Protocol

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Abstract

The Kyoto Protocol (KP) requires an accounting system that is meant to separate anthropogenic (including natural but human-induced) from natural greenhouse gas (GHG) emissions. This approach is not expedient for CO_2; over and above the standard argument that humanity's footprint on the carbon cycle is hard to distinguish from nature's. The choice of favouring an accounting system, which includes the human-induced part of nature "by agreement" but may be faulty, over an accounting system, which includes all natural sources but exhibits great uncertainties, is crucial for compliance. The extent to which neglect of full carbon accounting (FCA) and uncertainty in the Kyoto policy process may threaten the compliance process is unknown. The recently completed country-scale FCA study of Austria, our second such case study (the first being of Russia), builds a bridge from FCA to partial accounting under the KP and also considers uncertainty. The studies point to significant gaps in the methodology behind the KP for accounting GHG emissions, some of which had been foreseen in theory by studying carbon accounting vis-à-vis uncertainty on a systems-analysis basis, and assess how these gaps can be bridged.

Keywords: Kyoto Protocol; Full carbon accounting; Uncertainty; Verification; Net emission changes; Austrian Carbon Database

1. Introduction

The Kyoto Protocol (KP) contains the first legally binding commitments to limit or reduce the human-induced emissions of six greenhouse gas (GHG) groups (CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6) (UNFCCC, 1998a). Two crucial issues that had not appropriately been taken into account at the time of writing the KP relate to full carbon accounting (FCA) and accounting for uncertainty (Bolin, 1998; German Advisory Council on Global Change, 1998; Steffen *et al.*, 1998; Schulze *et al.*, 2002). The extent to which neglect of these two issues may threaten the KP and its compliance process is still unknown. Here we present the recently completed country-scale FCA study of Austria (Jonas and Nilsson, 2001), our second such case study, the first being of Russia (Nilsson *et al.*, 2000). The Austrian study builds a bridge from FCA to partial accounting systems such as that mentioned under the KP, and also considers uncertainty. The two country studies lead to conclusions of general relevance, some of which had been foreseen in theory by studying carbon accounting vis-à-vis uncertainty on a systems-analysis basis (Jonas *et al.*, 2000; Nilsson *et al.*, 2001; Victor, 2001), affirming that the KP requires major revision to appropriately deal with the Earth system.

We studied the detection of uncertain net emission changes (emission signals) in order to uncover the gaps in the methodology behind the KP for accounting GHG emissions and to assess how these gaps can be bridged. FCA is increasingly regarded by scientists as the relevant basis for negotiating GHG emission reductions. However, no practical guide exists that describes how FCA and, subsequently, logical partial carbon accounting (PCA) envisaged under the KP or the Revised 1996 IPCC Guidelines for National GHG Inventories (hereafter 1996 GHG Guidelines), should be carried out (Steffen *et al.*, 1998; UNFCCC, 2001; Schulze *et al.*, 2002). Accounting for uncertainty is addressed by the IPCC Good Practice Guidance for the anthropogenic sectors *Energy*, *Industrial Processes*, *Agriculture,* and *Waste* (Penman *et al.*, 2000). In the *Land Use Change and Forestry* (LUCF) sector, the uncertainty issue is believed to have been solved, at least for Article 3.4 activities (forest management, agricultural activities), with the introduction of country-specific allowable-sink caps during the Sixth and Seventh Sessions of the Conference of the Parties to the UNFCCC (UNFCCC, 2001; Schulze *et al.*, 2002). Nevertheless, the two issues are interrelated: the uncertainty issue cannot be resolved without properly addressing FCA, which is only one reason for predictions that the Kyoto Protocol will not accomplish its mission (Jonas *et al.*, 2000; Nilsson *et al.*, 2001; Victor, 2001).

Our Austrian study resulted in the production of a carbon-consistent database. The Austrian Carbon Database (ACDb) is organized into five modules: AGRO (Agriculture), CONSU/WASTE (Consumption and Waste), ENERGY (Energy), FOREST (Forestry), and PROD (Production) (Jonas and Nilsson, 2001). It uses publicly available data, including measured data, from around 1990 and emphasizes the transparent understanding of both mean values and uncertainties. The ACDb does not replace existing, officially agreed and widely accepted Austrian databases; instead, it provides a thematically less detailed but carbon-consistent standard that allows quantification of the uncertainties underlying these databases when they are used in a wider (Austrian-integrated) context. The database was designed using insights gained from IIASA's full carbon account for Russia (Nilsson *et al.*, 2000) and took into consideration other research and sectoral inventory or accounting studies carried out in Austria (Orthofer *et al.*, 2000; Weiss *et al.*, 2000; Winiwarter and Rypdal, 2001). However, in contrast to IIASA's Russian study, from the beginning the ACDb study explicitly evaluated uncertainty. Proper treatment of uncertainty is particularly critical in order to ensure that the Parties' compliance with the KP can be verified and that the Protocol will function (Fig. 1).

2. Theoretical investigations (deductive research)

Both FCA and accounting for uncertainty are closely associated with theoretical, top-down research (phase I; Section 2), which was carried out prior to the applied, bottom-up ACDb study (phase II; Section 3). The central issues addressed in phase I are methods for carbon accounting (Section 2.1), verification of systems exhibiting different dynamics (Section 2.2), and Kyoto-eligible market mechanisms (Section 2.3).

The definition of verification used as a reference was taken from the IPCC (Penman *et al.*, 2000: Annex 2). It is sufficient as it specifies verification toward the intended purpose of the KP, which can only be done from an atmospheric point of view: *What matters is what the atmosphere sees!*

2.1 Methods for carbon accounting

The KP's principal spatial reporting unit is partial GHG accounting (PGA) on the country scale. This implies that net emission changes of specified GHGs (including allowable sinks) are verifiable on this spatial scale over a fixed period of time from a base year. To account for changes in anthropogenic CO_2-equivalent emissions (referred to as fossil fuel or FF emissions) over time, the KP stipulates that mean values are to be compared on the basis of percentages (of both the base year and the commitment period) (UNFCCC, 1998a: Annex B). Subtracting mean values (referring either to the beginning and end of the commitment period or to the base year and commitment period) is proposed for LUCF activities. Changes in net LUCF emissions are added to the countries' change in FF emissions (UNFCCC, 1998b: Decision 9/CP.4; UNFCCC 2001).

The IPCC defines uncertainty with respect to two pre-defined points in time (Noble *et al.*, 2000: Section 2.3.7; Penman *et al.*, 2000: Chapter 6). Fig. 2 reflects this concept, based on two different types of uncertainty, total and trend uncertainty[1]. The figure shows that the knowledge of total uncertainty at only two times may lead to interpretational difficulties as to what the emission signal is and whether or not it is greater than its underlying uncertainty. A physically based concept, which we have named verification time (VT) concept, that grasps total uncertainty dynamically over time (see Section 2.2) provides a more adequate basis for dealing with this uncertainty–verification issue. Trend uncertainty is not favoured by researchers in the field of signal detection because it provides only second-order information (the change of a change); that is, trend uncertainty cannot verify a realised change in net emissions.

In contrast, global carbon research focuses largely on global-scale FCA. Atmospheric carbon measurements, including those of carbon isotopes and atmospheric oxygen as well as eddy-covariance measurements, allow for FCA on the global scale and offer the potential to distinguish between FF, terrestrial biospheric, and oceanic CO_2 sources and sinks. However, they do not distinguish between a *Kyoto biosphere* and a

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[1] The total (or level) uncertainty reflects our real diagnostic (accounting) capabilities, that is, the uncertainty that underlies our past as well as our current observations (accounts) and that we will have to cope with in reality at some time in the future (e.g., commitment year). The trend uncertainty reflects the uncertainty of the difference in net emissions between two years.

non-Kyoto biosphere[2,3]. The division of the terrestrial biosphere into a Kyoto and a non-Kyoto component thus eliminates the possibility of top-down verification.

Looking ahead, we consider the merging of the bottom up–top down (dual constrained) verification, as pursued by the global carbon research community, with the temporal verification, as demanded by the KP, as a major research challenge. Box 1 visualizes this challenge graphically.

2.2 *Verification of systems exhibiting different dynamics and uncertainties*

To analyze the impact of uncertainty on the verification of systems exhibiting different dynamics and uncertainties, we considered the aforementioned VT concept, which requires that the absolute change in net carbon emissions (signal), $|\Delta F_{net}(t_2)|$ at time t_2 (e.g., commitment year), with reference to time t_1 (e.g., base year) ($t_1 < t_2$), be greater than the total (absolute) uncertainty in the net carbon emissions at time t_2, $\varepsilon(t_2)$, that is, $|\Delta F_{net}(t_2)| > \varepsilon(t_2)$ (Jonas *et al.*, 1999). Under the assumption that linear approximations are sufficient for our purposes, we obtain an expression for the VT until the signal outstrips uncertainty:

$$\Delta t > \frac{\varepsilon(t_1)}{\left|\frac{dF_{net}}{dt}\right|_{t_1} - \left(\frac{d\varepsilon}{dt}\right)_{t_1}}, \qquad (1)$$

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[2] Articles 3.3 and 3.4 of the Kyoto Protocol stipulate that human activities related to LUCF since 1990 can be used to meet 2008–2012 commitments. Here, the part of the terrestrial biosphere that is affected by these Kyoto-compliant LUCF activities is referred to as the *Kyoto biosphere*, and its complement, as the *non-Kyoto biosphere*.

[3] Top-down FCA on sub-global scales faces a number of additional fundamental as well as practical limitations. See Jonas and Nilsson (2001: Section 3.1.5) for details.

requiring that the signal be greater than the change in uncertainty:

$$\left|\frac{dF_{net}}{dt}\right|_{t_1} > \left(\frac{d\varepsilon}{dt}\right)_{t_1} . \qquad (2)$$

Inequality (1) can be used to study the combination of net emissions of both Kyoto-eligible LUCF activities and FF burning on national scales. A great amount of uncertainty in the net emission account (numerator) and/or a relatively small rate of net emission change (denominator) owing to the implementation of LUCF activities may cause the VT to become very great (for simplicity, we assume no change in uncertainty here and in the following) (Fig. 3a, b). Therefore, a major political challenge in using the PGA framework of the KP is to demonstrate that no country can validly claim benefits by implementing LUCF (e.g., afforestation and reforestation) activities. By doing so, these countries would gain an advantage over others that manage only FF emissions that are verifiable at the time of commitment. In other words, by implementing LUCF activities, countries could potentially escape non-compliance sanctions by claiming that their carbon accounts require more time for verification.

2.3 Market mechanisms

The KP endorses market mechanisms that allow Annex I Parties to reduce emissions with and without non–Annex I Parties. To avoid breakdown of the carbon trading market due to competition and poor-quality reporting, Obersteiner *et al.* (2000) proposed a verification clause for emissions trading. They developed a system for pricing uncertainty in the process of recognizing uncertain emission reductions. Biospheric measures were not a priori disqualified despite the great uncertainty they carry. Temporal verifiability of national GHG emission changes—assured by a sufficiently small VT—was acknowledged and adhered to before permission was given to explore alternative economic paths. That is, system constraints (here, represented by the VT) were set before the economy was liberalized. This approach can be generalized with respect to environmental indicators of biospheric systems that go beyond the concerns of reducing carbon emissions. To ensure that additional environmental constraints (e.g., sustainability criteria) are fulfilled, they need to be introduced as an essential precondition before economic measures are permitted to take effect. It is this reasoning that underlies the numerous attempts to introduce the notion of sustainability and other environmental standards into the KP (Nilsson, 2001; Obersteiner *et al.*, 2001). However, the entire Kyoto policy process has run in the opposite direction so far: the economy has been liberalized while the environmental constraints have not yet been specified.

A weakness of economic approaches—the assumption of linear dynamics—is also illustrated by examination of Obersteiner *et al.* (2000). The physical reality is more complex. Annex I Parties typically exhibit a dynamical PCA behaviour in regard to FF emissions limited to CO_2 (PCA(FF: CO_2)) that is nonlinear on short time scales (Gusti and Jęda, 2002). The consequences can be vexing (Fig. 3c, d). The systems' properties, in our case the VT, behave nonlinearly as well (in fact, the VT begins to jump). Superimposing such a system on a system that exhibits a slow (linear or nonlinear) dynamical behaviour and/or great uncertainties makes matters worse. Instead of mastering nonlinear PCA(FF: CO_2) systems by minimising their non-verifiable time periods, we do the opposite and increase these periods by combining systems with different dynamics and/or uncertainties, for example, PCA(FF: CO_2) and PCA(LUCF) systems, or even PGA(FF: CO_2) and PGA(FF: non-CO_2) systems. A physically adequate treatment would require interdependent cost functions for emission and uncertainty reductions, as well as ensured verifiability and the preservation of environmental standards.

Precautionary thinking leads to the conclusion that the KP must separate systems and tackle them individually. Even if systems are treated separately, highly complex problems remain that require systems analysis, taking into account environmental and possibly other considerations.

3. Insights from experience (inductive research)

A specific insight gained during work on the ACDb FOREST module relates to the availability of the "two-sided" statistics that Austria as a "data-rich" country provides in a number of cases (Section 3.1). These generally disagree, offering the rare possibility of scrutinising the quality of country reviews where the countries have provided only "one-sided" statistics. In the short term, increased data richness will probably uncover more such predicaments. The national-scale implications of these "two-sided" statistics are followed up in the ENERGY module (Section 3.2).

3.1. Specific insight

In assembling the FOREST module for 1988–1994, the disagreements between two "two-sided" statistics had to be overcome. The first disagreement is associated with the exploitation–harvest discrepancy between Austria's Forest Inventories and the Austrian Wood Balance. The second disagreement relates to the conservation of matter, namely, between the left- and right-hand sides of the equation *temporal change in standing stock = net growth minus exploitation*. To bridge these statistical inconsistencies, we utilized the concept of an *uncertainty range*, covering the measured biases of the two individual statistics plus each of their standard deviations (random errors) (Nilsson *et al.*, 2000: Section 2.5; Jonas and Nilsson, 2001: Section 2.2.2)[4].

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[4] This uncertainty concept acknowledges the existence of both available knowledge and lack of knowledge when accounting net carbon emissions. However, lack of knowledge is addressed in a way that is necessary but not sufficient. The concept is in accordance with the International Organization for Standardization (ISO, 1995), which distinguishes between "Type A" and "Type B" uncertainties. Type A is the evaluation of uncertainty by the statistical analysis of a series of observations. Type B is the

Applying this concept twice, we can thus assign an overall relative uncertainty to the mass balance equation that takes the exploitation–harvest discrepancy into account. This relative uncertainty is >40% and falls into class 5 of our scale, while the left- and right-hand sides of the mass balance equation fall into classes 5 and 4 (20–40%), respectively[5].

How meaningful is a KP embedded with uncertainties derived from non-standardised systems views, or from "one-sided" statistics? The accounting of forest-related LUCF activities follows the *temporal change in standing stock* (i.e., the left-hand side of the law of conservation of matter) (UNFCCC, 1998b: Decision 9/CP.4; UNFCCC 2001). This side of the equation reveals the greater uncertainty, potentially even greater than 100% (if non-permanent survey plots are used that do not permit the

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evaluation of uncertainty by any other means (see Jonas and Nilsson, 2001: Section 4.1.2 for details). For the ACDb, we chose the 68% confidence total to report uncertainty because striving for a higher, purely mathematical confidence level cannot be justified physically as long as we have to cope with uncertainty ranges as a result of inconsistent or missing knowledge in realizing full carbon accounts.

[5] In the ACDb, the calculation of uncertainties follows the law of uncertainty propagation, which requires that the data be normally or "close-to-normally" distributed and not correlated among one another. However, this may not always be the case, and the need for pragmatic approximations arises. In addition, in a great number of cases it turns out to be advisable for physical reasons to simplify calculations. We found all our (total) uncertainty calculations and approximations to be quite robust when utilising five relative uncertainty classes: class 1: 0–5%, class 2: 5–10%, class 3: 10–20%, class 4: 20–40%, and class 5: >40%. The definition of these classes is arbitrary and attempts to satisfy simple practical considerations as to how many different intervals we wanted to resolve (see Jonas and Nilsson, 2001: Section 4.1.3 for details). The relative uncertainty classes constitute a robust means to get an effective grip on uncertainties. The reporting of exact uncertainties is not justified in light of the inconsistent accounting of carbon under the KP and for the reasons mentioned in footnote no. 4.

reduction of uncertainty due to correlation). Two large numbers are subtracted from each other and the small difference between them entails a great uncertainty.

To conclude, PCA under both the 1996 GHG Guidelines and the KP does not ensure that the physical law of conservation of matter is rigorously preserved in deriving net biospheric sink strengths. (Compliance with this physical boundary condition can lead to greater uncertainty in the accounting). The accounting of net biospheric sink strengths under the KP is least trustworthy, exhibiting unacceptably great uncertainties that may have crucial implications for implementing Article 3.3 activities (afforestation, reforestation, deforestation) under the Protocol.

3.2. National-scale implications

In the ACDb ENERGY module, the national-scale effect on uncertainty was studied using different accounting schemes that are consistent with one another. These calculations facilitate a direct and transparent understanding of both mean values and uncertainties. The three accounting schemes considered fall into the source/sink categories of the 1996 GHG Guidelines: (A) FCA as in the ACDb; (B) PCA following the 1996 GHG Guidelines; and (C) FCA following the 1996 GHG Guidelines[6]. Three distinct and relevant results are shown in Table 1:

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[6] (A) FCA as in the ACDb. This accounting scheme is determined by the logic of the ACDb. Emissions from ENERGY are derived from the *Österreichische Luftschadstoff-Inventur* (OLI, Austrian Air Pollutant Inventory) by taking into consideration only the energy-related source categories 1 (Energy), 2 (Industrial processes: Iron and steel production: Combustion and calcination), and 6 (Waste: Electrification). The CO_2 emissions that result from the burning of biogenic fuels and fuelwood enter the accounting. The remaining emissions/removals appear—neglecting minor inconsistencies (see Jonas and Nilsson, 2001: Section 4.2.5 for details)—in the other modules of the ACDb.

1. The uncertainty of CO_2 dominates the total uncertainty in all accounting schemes. FF-related CO_2 emissions (i.e., IPCC source categories 1 [Energy], 2 [Industrial processes], and 6 [Waste: Electrification]) exhibit the smallest relative uncertainty classes, a situation that is typical for many countries.

2. An attempt to carry the bridging experience of "two-sided" statistics with the ACDb, applied to the FCA as under the 1996 GHG Guidelines, simulates and uncovers an effect arising from uncertainties of the type *emissions minus removals*. Reducing the total national CO_2 emissions by IPCC category 5 (LUCF) increases their relative uncertainty (here, from class 1 to 3) under FCA, but not under PCA. This is because a practically identical LUCF sink strength (9.15 versus 9.21 10^6 tC yr^{-1}, both of which are estimates of the sink strength of Austria's exploitable forest) with a greater relative uncertainty class (class 5 versus class 3) enters the FCA

(B) PCA (or PGA) following the 1996 GHG Guidelines. The emissions from/removals by all six source/sink categories are considered and taken from OLI, following Austria's official reporting procedures. The uncertainties underlying this accounting scheme were investigated by W. Winiwarter and R. Orthofer (2000) for CO_2, CH_4, and N_2O. (For an advanced comparison of results, we carry along N_2O in the calculations.) The burning of biogenic fuels, fuelwood, and peat as well as the on-site burning of straw is treated as CO_2 neutral.

(C) FCA (or FGA) following the 1996 GHG Guidelines. This accounting scheme is similar to the one in (B), but it utilizes non-energy-related emissions/removals from the ACDb to the extent they are specified (see Jonas and Nilsson, 2001: Section 4.2.5 for details). The CO_2 emissions that result from the burning of biogenic fuels and fuelwood as well as from the on-site burning of straw enter the accounting. (For an advanced comparison of results, we carry along N_2O in the calculations.)

compared with the PCA[7]. We recall that a greater uncertainty induces a greater VT.

3. Superimposing the highly uncertain emissions of the non-CO_2 GHGs with the less uncertain CO_2 emissions can also induce the aforementioned effect[8]. The overall emissions carry a greater relative uncertainty and thus result in a greater VT.

4. Conclusions

Our top-down (Section 2) and bottom-up (Section 3) research shows that the way in which national emissions are inventoried in the KP is in urgent need of fundamental methodological improvements. To guide the Protocol toward success:

1. A robust FCA system (embedded in a proper full GHG accounting system) that permits the quantification of uncertainties is required. Furthermore, the biosphere must be treated as one system and must not be split into a *Kyoto biosphere* and a *non-Kyoto biosphere.*

2. The two-points-in-time IPCC uncertainty concept must be replaced by a robust signal detection concept that allows temporal verification. Furthermore, bifurcated rules (if not fully separate protocols) are needed that treat the more easily verified fluxes (especially FF CO_2) differently from those that are more uncertain (notably, CO_2 sinks).

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[7] See Tab. 1: PGA and FGA Following the 1996 GHG Guidelines; Lines: Total w/o LUCF and Total; Column: Uncertainty (CO_2).

[8] See Tab. 1: PGA Following the 1996 GHG Guidelines; Line: Total; Columns: Uncertainty (CO_2) and Uncertainty (CO_2+CH_4+N_2O).

3. An understanding must be developed of what the environmental criteria should be under the KP. Environmental objectives (e.g., sustainability criteria) are an essential precondition before economic measures are permitted to take effect.

Acknowledgements

We are very much indebted to A. Shvidenko for his constructive suggestions and E. Bergschneider and A. John for their editorial support. The IIASA Forestry Project gratefully acknowledges the financial support from the Austrian Federal Ministry of Education, Science and Culture.

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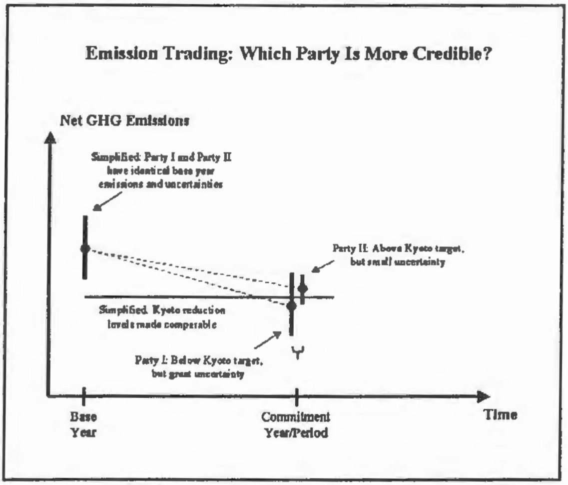


Fig. 1. Emission Trading: Which Party Is More Credible?

Simplified graphical representation illustrating the importance of uncertainty in the context of the KP, here addressing the crucial question of credibility while presupposing verifiable net emission changes. The uncertainty intervals of both Party I and Party II encompass the same Kyoto target, but which Party is more credible for emission trading? 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.

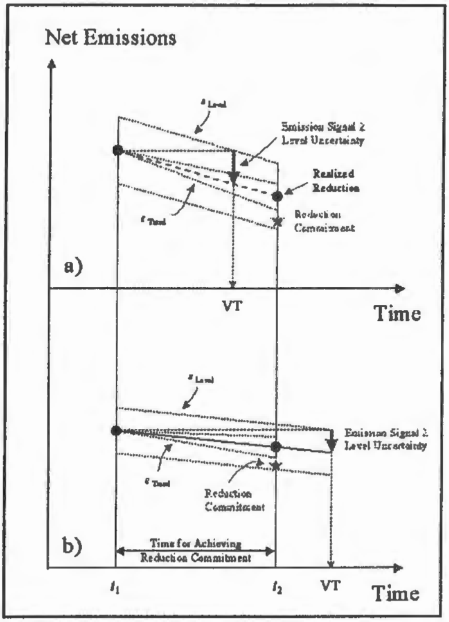
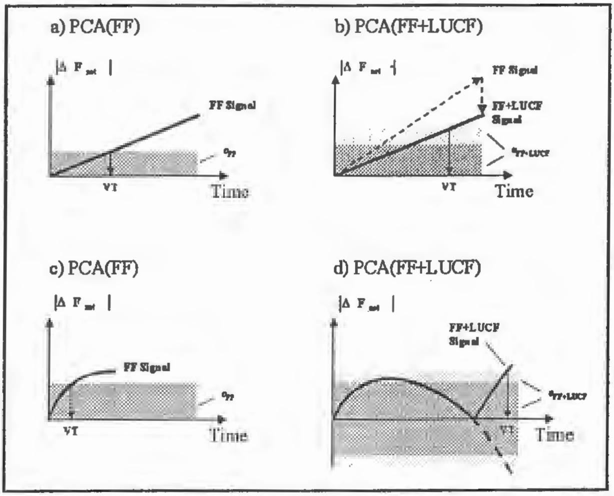


Fig. 2. VT Concept versus IPCC Uncertainty Concept

Simplified (linear) graphical representation of the VT concept (as defined in Section 2.2) versus the two-points-in-time (here, t_1 and t_2) assessment *realized emission change vis-a-vis uncertainty*, where the two uncertainties currently discussed (see text) are: total uncertainty (ε_{Total}) [here, $\varepsilon_{Total}(t_2) = \varepsilon_{Total}(t_1)$] and trend uncertainty (ε_{Trend}). The signal's dynamics determines the time (VT) until the signal outstrips its underlying total uncertainty, as shown with the help of **a)** $VT < t_2 - t_1$ and **b)** $VT > t_2 - t_1$. In case b) the emission signal is not yet detectable at t_2. By contrast, the two-points-in-time assessment *realized emission change versus (total) uncertainty* of both a) and b) leads to (proportionate) compliance at t_2.


a) PCA(FF)

b) PCA(FF+LUCF)

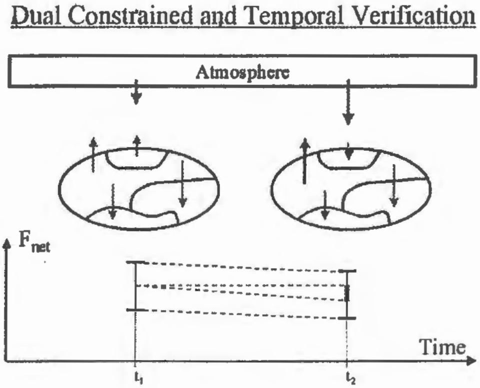
c) PCA(FF)

d) PCA(FF+LUCF)

Fig. 3. Linear and Nonlinear Behaviour of VT

Simplified illustration of the linear (a, b) and nonlinear (c, d) behaviour 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 (ε_{FF} and $\varepsilon_{FF+LUCF}$, respectively, with $\varepsilon_{FF} < \varepsilon_{FF+LUCF}$) and thus different VTs. c, d): Here, the FF+LUCF signal exhibits a jumpy VT behaviour as a consequence of combining a nonlinear FF signal by a LUCF signal with slow dynamics. (To give a better overview, the LUCF signal has been omitted in d).) The linear and nonlinear behaviour of the VT can be easily checked by slowly increasing the width of the light-grey bar (ε_{LUCF}), beginning from zero (Gustl and Jęda, 2002).

Box 1. Dual Constrained and Temporal Verification



Assume that we were able to repeatedly carry out dual constrained FCA for some 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 higher 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 (total) 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, for example, the change in the net emissions at t_2 disappears within the 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 more than this when explicitly considering time and asking when the emission signal is outstripping uncertainty. To handle such situations, we have to additionally utilize signal detection techniques to achieve robust and sound verification.

Table 1 Differences in the Accounting for Austria

Austria's 1990 energy-related emissions from the IPCC source categories 1 (Energy), 2 (Industrial processes: Iron and steel production: Combustion and calcination), and 6 (Waste: Electrification) (A). This ACDb-consistent accounting is contrasted with an accounting according to the 1996 GHG Guidelines, which is PGA based (B), and the same accounting but adjusted for FGA (C).

	CO_2 10^6 t CO_2	Uncertainty Class	$CO_2+CH_4+N_2O$ 10^6 t CO_2 eq.	Uncertainty Class
A. FCA According to the ACDb				
Energy	57.03	Class 1	57.26	Class 1
Industrial Processes	7.74	Class 1	7.74	Class 1
Solvent and Other Product Use				
Agriculture				
Land-Use Change and Forestry				
Waste	0.20	Class 3	0.20	Class 3
Total	**64.97**	**Class 1**	**65.20**	**Class 1**
B. PGA Following the 1996 GHG Guidelines				
Energy	49.69	Class 1	50.79	Class 1
Industrial Processes	12.70	Class 1	12.89	Class 1
Solvent and Other Product Use	0.54	Class 4	0.77	Class 4
Agriculture			5.59	Class 5
Land-Use Change and Forestry	- 9.21	Class 3	- 9.21	Class 3
Waste	0.60	Class 4	6.81	Class 4
Total w/o LUCF	**63.54**	**Class 1**	**76.85**	**Class 1**
Total	**54.32**	**Class 1**	**67.64**	**Class 2**
C. FGA Following the 1996 GHG Guidelines				
Energy	57.03	Class 1	57.85	Class 1
Industrial Processes	12.45	Class 1	12.64	Class 1
Solvent and Other Product Use	0.54	Class 4	0.77	Class 4
Agriculture	0.05	Class 5	6.84	Class 4
Land Use Change and Forestry	- 9.15	Class 5	- 9.15	Class 5
Waste	0.77	Class 4	6.97	Class 4
Total w/o LUCF	**70.84**	**Class 1**	**85.07**	**Class 1**
Total	**61.69**	**Class 3**	**75.92**	**Class 3**