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Interim Report **IR-00-061**

How to Go From Today's Kyoto Protocol to a Post-Kyoto Future that Adheres to the Principles of Full Carbon Accounting and Global-scale Verification?

A Discussion Based on Greenhouse Gas Accounting, Uncertainty and Verification

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Summary

The Kyoto Protocol is often described as a good first step towards reducing greenhouse gas emissions into the atmosphere. At its upcoming sixth meeting in The Hague from 13–24 November 2000, the Conference of the Parties (COP 6) will decide on how to make the Kyoto Protocol operational. One of the major concerns is to ensure that actions taken are environmentally credible as well as economically efficient. The meeting's success is going to be measured by the support it will receive by both Annex I and non-Annex I Countries and by the Protocol's early entry into force.

One of the issues that has received considerable attention is the inclusion of biospheric sinks into the Protocol to offset anthropogenic emissions. Much knowledge has already been compiled in regard to this controversially debated issue, including problems related to: permanence/non-permanence of biological sinks, distinguishing between directly and indirectly human-induced effects, setting baselines and defining additionality, grasping leakages, schemes for accounting greenhouse gases, uncertainty and verification, etc.

Many of these problems are not only unique to biospheric sinks, but are generally valid. They are discussed in detail within numerous scientific and expert communities, however, leaving many of these problems unsatisfactorily resolved. Here, we ask four key questions:

> "Where do we want to go?" "What do we know?" versus "What do we not know?" "Which difficulties do decision-makers face in deciding how to get there?"

and attempt to balance insights into fundamentals and principles across disciplines by way of discussion.

Our discussion is driven by physical and economic arguments. It addresses the aforementioned questions by focusing on three issues: greenhouse gas accounting (here restricted to carbon accounting), uncertainty and verification. We embed into our discussion the question of whether or not economic efficiency and increase in the quality of verification can be achieved simultaneously when including biospheric sinks into the Kyoto Protocol.

If the initial question "Where do we want to go?" is answered by "We want to reduce greenhouse gas emissions", recognizing that emission reductions must be measurable and confirmable by an impartial observer in the atmosphere, our discussion leads us to the question decision-makers are facing now:

How do we go from a Kyoto Protocol, under which:

- carbon is insufficiently (partially) accounted;[1]
- verification is inadequately understood; and
- the beneficialness of actions to the atmosphere cannot be proven;

to a post-Kyoto future that:

- considers Full Carbon Accounting (FCA)[1] by all nations; and
- can be verified on the global scale?

For the purpose of illustration, we consider two extreme views, termed a physical view and an economic view, of how this future may be achieved in a stepwise approach, assuming initially that decision-makers will restrain from realizing full carbon accounting now. The physical view prioritizes the quality of verification (as seen from an atmospheric point of view) over economic efficiency. It, therefore, goes for global-scale bottom up–top down verification of a reduced accounting system that excludes biospheric sink options initially, but requires that all nations join the Protocol (in consideration of their common but differentiated responsibilities). By way of contrast, the economic view ranks the establishment of a functioning and economically efficient carbon market higher than the quality of verification (as seen from an atmospheric point of view). It, therefore, accepts any clear verification rules initially, but requires that uncertainty (i) becomes an integral part of the reporting system and (ii) specifies by how much market participants have to undershoot their assigned Kyoto targets. Based on this exercise, we conclude that:

1. the Kyoto Protocol in its current form is inadequate.
2. the Protocol requires major modifications, no matter how it attempts to get to this Kyoto future. These modifications deal with the way carbon is accounted, and how uncertainty and verification are addressed.
3. scientists and experts are not in a position to identify **the** optimal path of how to get to this Kyoto future.
4. the Protocol does not permit (for given emission limitation or reduction objectives) the option of including biospheric sinks in a way that is both economically efficient and increases the quality of verification (as seen from an atmospheric point of view). Instead, our discussion suggests that a trade-off exists between economic efficiency versus quality of verification.

Thus, looking ahead, the introduction of FCA is considered now to be the most needed step forward. Emission reductions, including already eligible activities that enhance biospheric sinks, must be measured within this wider context. The serious problem of addressing uncertainty and verification remains. The beneficialness of actions to the atmosphere can still not be proven. However, at least in regard to unaccounted sources and sinks this problem appears less crucial. FCA will also help to put biospheric sink options that are discussed, currently or in the future, into a relative perspective. Preserving existing forests and halting deforestation, e.g., will gain importance and come into focus. Conclusion 4 appears to stay valid.

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[1] For our definitions of Partial Carbon Accounting (PCA) and Full Carbon Accounting (FCA) see *Acronyms, Definitions and Nomenclature.*

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How to Go From Today's Kyoto Protocol to a Post-Kyoto Future that Adheres to the Principles of Full Carbon Accounting and Global-scale Verification?

A Discussion Based on Greenhouse Gas Accounting, Uncertainty and Verification

Matthias Jonas, Michael Obersteiner and Sten Nilsson

1. What is the Goal of the Kyoto Protocol?

The Kyoto Protocol commits Annex I Parties to individual, legally-binding targets to limit or reduce their greenhouse gas emissions, adding up to a total cut of at least 5% in terms of CO_2 equivalents from 1990 levels in the period 2008–2012. The targets cover the emissions of six relevant greenhouse gases (GHGs): carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6).

Some specified activities in the land-use change and forestry category (so far: afforestation, deforestation and reforestation) that emit or remove carbon dioxide from the atmosphere are also covered. All changes in emissions, and in removals by so-called sinks, go into the same basket for accounting purposes (FCCC, 2000; see also Jonas *et al.*, 1999a, b; Nilsson *et al.*, 2000).

This paper is based on the assumption that the net emission reduction to be achieved under the Kyoto Protocol must be detectable, i.e., measurable and confirmable by an impartial observer, in the atmosphere.

2. How to Reach the Kyoto Goal?

The following two questions, namely

1. Where does carbon accounting currently stand? and
2. What are the scientific requirements stipulated by the Kyoto goal?

have been addressed in the Appendix. They lead to the crucial question that underlies the Kyoto Protocol:

How do we go from a Kyoto Protocol, under which:

- carbon is only partially accounted;
- verification is inadequately understood; and
- the beneficialness of actions to the atmosphere cannot be proven;

to a post-Kyoto future that

- considers Full Carbon Accounting (FCA) by all nations; and
- can be verified on the global scale?

That is, we know where we stand and what the post-Kyoto future is. But we do not yet know **how** to get there.

For the purpose of illustration, we consider two extreme views, termed a physical view and an economic view, of how this future may be achieved in a stepwise approach. **We assume initially that decision-makers will restrain from realizing full carbon accounting now**. Each view follows disciplinary fundamentals or principles that are considered most important. The physical fundamentals are summarized in the Appendix, while the economic principles including first-order insights are laid out in Obersteiner *et al.* (2000b). Additional information can be found in Jonas *et al.* (1999a, b), Nilsson *et al.* (2000), and Obersteiner *et al.* (2000a).

The physical view prioritizes the quality of verification (as seen from an atmospheric point of view) over economic efficiency. It, therefore, goes for global-scale bottom up–top down verification (see Appendix B.3) of a reduced accounting system that excludes biospheric sink options initially, but requires that all nations join the Protocol (in consideration of their common but differentiated responsibilities). By way of contrast, the economic view ranks the establishment of a functioning and economically efficient carbon market higher than the quality of verification (as seen from an atmospheric point of view). It, therefore, accepts any clear verification rules initially, but requires that uncertainty (i) becomes an integral part of the reporting system and (ii) specifies by how much market participants have to undershoot their assigned Kyoto targets.

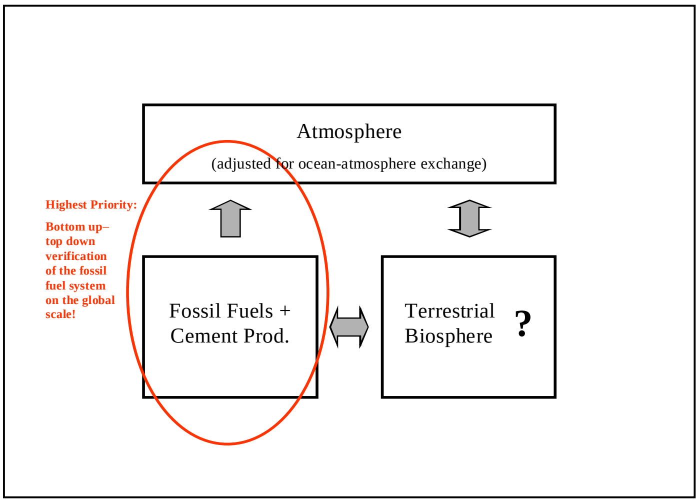
2.1 A Physical View

Concern	Emission reductions claimed by Annex I Countries cannot be verified on the global scale. Thus, non-Annex I Countries may consider the Kyoto Protocol an ‘easy way out’ for Annex I Countries to escape their commitments. The Kyoto Protocol will fail if non-Annex I Countries will not join in.
Aim	To increase the credibility of the Kyoto Protocol and, thus, to render it capable of becoming accepted by all nations as the relevant policy tool for reducing GHG emissions.

Preferred Strategy	Verification on the global scale functions bottom up–top down and may be approached in a two-step procedure: 1st Step: Verification of the fossil fuel system (scientifically possible; to be realized now); 2nd Step: Handling of the entire biospheric system (scientific knowledge inadequate; to be realized later).
Key Element of the Strategy	The key element of this two-step procedure is that it prefers bottom up–top down verification for part of the system, namely the fossil fuel system, over an enlarged system, namely the fossil fuel system plus the Kyoto biosphere, where the Kyoto-biosphere cannot be verified in a bottom up–top down fashion (but only, at best, temporally on sub-global scales). For the increase of the Protocol's credibility, • adherence to a verification that functions vertically, namely bottom up–top down, is considered to be more important than the search for economic opportunities outside the vertical verification structure (i.e., the fossil fuel system). • accounting the fossil fuel emissions of all nations bottom-up and verifying them top-down are considered to be more important than an incomplete inclusion of the biosphere.
Requirements	A bottom up–top down verification of the fossil fuel system requires that **all** nations join the Kyoto Protocol (in consideration of their common but differentiated responsibilities, an issue that is left to decision-makers).

Underlying Assumption

Bottom up–top down verification of the fossil fuel system does **not** imply global-scale verification of the entire (fossil fuel + biospheric) system:



This is because emissions from the entire system to the atmosphere may increase, although emissions from the fossil fuel system are limited (or reduced). Conditions prevailing in the fossil fuel system may trigger adverse activities or processes within the terrestrial biosphere (e.g., increased use of fuel wood, followed by vast deterioration of ecosystems) that counteract and even compensate the emissions from the fossil fuel system.

However, bottom up–top down verification of the fossil fuel system is assumed to be more insightful than accounting an enlarged system, namely the fossil fuel system plus the Kyoto biosphere, where the Kyoto-biosphere cannot be verified alike (but only, at best, temporally on sub-global scales).

Reasoning

By way of contrast to the economic view, this two-step verification procedure provides at least **a** handle (i.e., intermediate, bottom up–top down verification), which is insightful though not perfect, and which we can grasp on our way to reaching the post-Kyoto future (FCA practiced by all nations; bottom up–top down verification on the global scale).

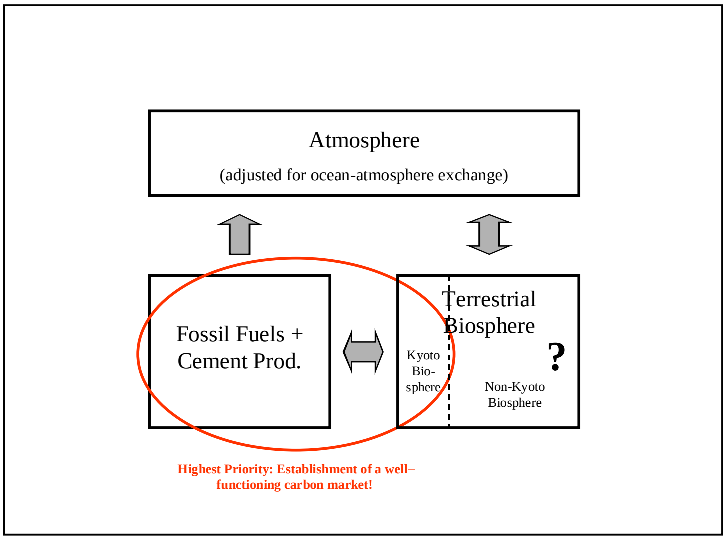
Further Specifications	• Focus on the fossil fuel system initially, the most dynamic system on the scale of the current century. • Deal with the entire biosphere later. • Here, the question whether or not and, if yes, to which extent flexible mechanisms (i.e., emission trading, joint implementation, clean development mechanism) can be used within the fossil fuel sector, is left to the decision-makers. • Accept that the concept of subtracting mean values is applied on the national scale as well as on the scale of projects. However, uncertainties need to be considered in the fossil fuel accounts on both scales. Here, the question when and how this is done, is left to decision-makers. The only boundary condition that **cannot** be considered negotiable: No later than a bottom up–top down verification of the national fossil fuel accounts has been accomplished and a potential mismatch quantified, a mechanism must be in place that permits to allocate this mismatch among all nations.
Strengths	• The Focus is back on the most relevant and dynamic system on the scale of the current century, the fossil fuel system. • The terrestrial biopsheric system (including deforestation, preservation of existing forests, etc.) can be addressed separately. • Non-Annex I Countries may not consider the Kyoto Protocol an ‘easy way out’ for Annex I Countries to escape their commitments by making use of a Kyoto biosphere, which cannot be verified bottom up–top down (but only, at best, temporally on sub-global scales). • Bottom up–top down verification of the fossil fuel system provides at least **a** handle, which is insightful though not perfect, and which we can grasp on our way to reaching the post-Kyoto future (bottom-up FCA verified on the global scale).

Weaknesses	• The Kyoto Protocol is driven by economics. Annex I Countries may refuse to join in if they cannot establish a functioning carbon market and take advantage of economic opportunities. • The Kyoto Protocol needs to be modified (exclusion of the biospheric system). • To grant success, all nations have to join the Kyoto protocol (in consideration of their common but differentiated responsibilities). • Bottom up–top down verification of the fossil fuel system is insightful but does not imply global-scale verification of the entire (fossil fuel + biospheric) system. • A mechanism of how to handle uncertainties on the national scale as well as on the scale of projects has still to be negotiated.

2.2 An Economic View

Concern	Emission reductions claimed by Annex I Countries cannot be verified. However, Annex I Countries require clear verification rules to establish a functioning carbon market that minimizes false reporting, and to assess the effectiveness of measures that reduce anthropogenic emissions or enhance biospheric sinks. The Kyoto Protocol will fail, if Annex I Countries will not join in because they cannot establish a functioning carbon market and take advantage of economic opportunities.
Aim	To increase the credibility of the Kyoto Protocol and, thus, to render it capable of becoming accepted by all nations as the relevant policy tool for reducing GHG emissions.
Preferred Strategy	To reach the post-Kyoto future (FCA practiced by all nations; bottom up–top down verification on the global scale), a two-step procedure is proposed: 1st Step: Establishment of a carbon market that functions under **any** clear verification rules on sub-global scales (to be realized now); 2nd Step: Global market participation by all nations (in consideration of their common but differentiated responsibilities) and introduction of FCA for handling the remainder of the biosphere (to be realized later).

Key Element of the Strategy	The key element of this two-step procedure is that it aims, first and foremost, at establishing a carbon market that functions under **any** clear verification rules on sub-global scales. This carbon market encompasses the fossil fuel system and does not exclude the Kyoto biosphere. Verification on the global scale by participation of all nations in the carbon market and the introduction of FCA receive subordinate priority. For the increase of the Protocol's credibility, • adherence to a temporal verification scheme that minimizes false reporting including biases and permits assessing the effectiveness of emission reduction or biospheric sink measures is considered most important. To these ends, uncertainty as a compliance tool is introduced. By becoming an integral part of the reporting system, uncertainty defines by how much market participants have to undershoot their assigned Kyoto targets. • turning any temporal verification scheme into a successful and effective market mechanisms is considered to be more important than the quality of verification itself.
Requirements	To successfully minimize false reporting and assess the effectiveness of emission reduction or biospheric sink measures, temporal verification requires taking uncertainty and undershooting of assigned Kyoto targets into account.

Underlying Assumption	Temporal verification of emission reduction and biospheric sink measures in the fossil fuel system plus the Kyoto biosphere does not aim at global-scale verification initially. However, temporal verification of these measures in consideration of uncertainty as a compliance tool is assumed to minimize biases to the largest extent possible. Moreover, it is assumed that this compliance mechanism works succesfully all the way until global market participation has eventually been achieved (2nd Step, with FCA not yet realized). At this point, the fossil fuel system of the combined (fossil fuel + Kyoto biosphere) system can be verified bottom up–top down on the global scale (as under 2.1); however, **not** the Kyoto biosphere [and also **not** the entire (fossil fuel + biospheric) system]. 
Reasoning	By way of contrast to the physical view, this two-step economic procedure ensures that at least a well-functioning carbon market is established. Introducing uncertainty as a compliance tool, which defines by how much market participants have to undershoot their assigned Kyoto targets, minimizes biases to the largest extent possible.

Further Specifications	• Focus on the establishment of a well-functioning carbon market initially, the most important economic prerequisite. • Deal with global market participation by all nations (in consideration of their common but differentiated responsibilities) and introduce FCA for handling the remainder of the biosphere later. • The use of flexible mechanisms (i.e., emission trading, joint implementation, clean development mechanism) throughout the fossil fuel system and the Kyoto biosphere is principally supported. • **Any** clear verification rules are accepted. Uncertainty must be introduced. • Temporal verification in combination with uncertainty will minimize false reporting including biases and permit assessing the effectiveness of emission reduction or biospheric sink measures.
Strengths	• The Kyoto Protocol is driven by economics. Annex I Countries will join in because they can establish a functioning carbon market and take advantage of economic opportunities. • **Any** temporal verification, in combination with uncertainty, will minimize false reporting including biases and permit assessing the effectiveness of emission reduction or biospheric sink measures. • Market credibility and stable market expectations are crucial and are ranked higher than the compliance with short-term, high-quality verification conditions. • Not all nations have to join the Kyoto Protocol in order to establish the carbon market.

Weaknesses	• Because of **a** verification mechanism, which works temporally on sub-global scales and which, in combination with uncertainty, has not yet been proven to minimize biases successfully, non-Annex I Countries may consider the Kyoto Protocol still an 'easy way out' for Annex I Countries to escape their commitments. • Temporal verification on sub-global scales is preferred over an eventual bottom up–top down verification of the fossil fuel system. Therefore, this 'bottom up–top down verification handle', which is insightful though not perfect, and which we could grasp on our way to reaching the post-Kyoto future (bottom-up FCA verified on the global scale), may not become as quickly available as it would be by pursuing the physical view. • Assigned emission limitation or reduction commitments of Annex I Countries need to be perceived differently. They need to be undershot by an amount that is defined by uncertainty. • The inclusion of biospheric sinks into the Protocol creates additional problems. • The discussion of current biospheric sink options receives more attention than justified. Important biospheric issues (e.g., halting deforestation, preserving existing forests, etc.) are getting out of focus.

2.3 Conclusions

Our conclusions based on this exercise are as follows:

1. The Kyoto Protocol in its current form is inadequate.
2. The Protocol requires major modifications, no matter how it attempts to get to this Kyoto future. These modifications deal with the way carbon is accounted, and how uncertainty and verification are addressed.
3. Scientists and experts are not in a position to identify **the** optimal path of how to get to this Kyoto future.
4. The Protocol does not permit (for given emission limitation or reduction objectives) the option of including biospheric sinks in a way that is both economically efficient and increases the quality of verification (as seen from an atmospheric point of view). Instead, our discussion suggests that a trade-off exists between economic efficiency versus quality of verification.

3. Looking Ahead: The Important Next Step

Recalling the crucial question that underlies the Kyoto Protocol, namely:

How do we go from a Kyoto Protocol, under which:

- carbon is only partially accounted;
- verification is inadequately understood; and
- the beneficialness of actions to the atmosphere cannot be proven;

to a post-Kyoto future that:

- considers FCA by all nations; and
- that can be verified on the global scale?

as well as the conclusions of the previous section, we consider the introduction of FCA to be the most needed step forward. Emission reductions, including already eligible activities that enhance biospheric sinks, must be measured within this wider system. The problem of addressing uncertainty and verification remains. The beneficialness of actions to the atmosphere can still not be proven. However, at least in regard to unaccounted emission sources and sinks this problem appears less crucial. FCA will also help to put biospheric sink options that are discussed, currently or in the future, into a relative perspective. Preserving existing forests and halting deforestation, e.g., will come into focus. Conclusion 4 of the previous section appears to stay valid.

Appendix

The Appendix focuses on two questions: (1) Where does carbon accounting currently stand? and (2) what are the scientific requirements stipulated by the Kyoto goal? Appendix A deals with the first question, Appendix B with the second question. Their synopsis leads to the question, which is posed in Section 2:

How do we go from a Kyoto Protocol, under which:

- carbon is only partially accounted;
- verification is inadequately understood; and
- the beneficialness of actions to the atmosphere cannot be proven;

to a post-Kyoto future that

- considers full carbon accounting by all nations; and
- that can be verified on the global scale?

The Appendix is based on the assumption that the net emission reduction to be achieved under the Kyoto Protocol must be detectable, i.e., measurable and confirmable by an impartial observer, in the atmosphere (cf. Section 1).

In the Appendix we restrict greenhouse gas accounting to carbon accounting and in this context we refer preferably, but not necessarily, to CO_2, the most researched of the GHGs.

A Where Does Carbon Accounting Currently Stand?

A.1 Accounting Carbon Spatially

Global-scale Carbon Accounting

In contrast to quantifying the fossil fuel system, the oceanic system and the terrstrial biospheric system globally, measuring atmospheric CO_2 (and its rate of change) is straightforward and highly accurate. In fact, today's atmospheric measurements (e.g., measurements based on the isotopic composition of atmospheric CO_2, ideally in combination with the measurement of atmospheric O_2) even offer the potential to distinguish between fossil fuel, terrestrial biospheric and oceanic CO_2 sources and sinks (e.g., Battle *et al.*, 2000), but not between a 'Kyoto biosphere' and a 'non-Kyoto biosphere' (cf. Figure A-1). Whether or not this will be possible in the future is another question. [However, it can be safely stated that this will not happen in the immediate future (e.g., MPI, 1999).]

There are two distinct features that characterize atmospheric measurements: (1) They are complete, meaning that they allow for Full Carbon Accounting (FCA; see also *Acronyms, Definitions and Nomenclature*); and (2) they are global. It is this combination, which predestinates global atmospheric measurements as an ultima ratio measure for what is happening to the atmosphere.

- **Atmospheric carbon measurements allow for FCA and they are global.**
- **Atmospheric measurements offer the potential to distinguish between fossil fuel, terrestrial biospheric and oceanic CO_2 sources and sinks, but not between a ‘Kyoto biosphere’ and a ‘non-Kyoto biosphere’.**

National-scale Carbon Accounting

There are two methods of accounting carbon on the national scale, the relevant scale for accounting carbon under the Kyoto Protocol: partially and fully.

By far, the most practiced form of carbon accounting is termed Partial Carbon Accounting (PCA; see also *Acronyms, Definitions and Nomenclature*). For instance, PCA is applied in the context of the UN Framework Convention on Climate Change (FCCC), under which nations have to assess their contributions to sources and sinks of CO_2 and to evaluate the processes that control CO_2 accumulation in the atmosphere. The same is true under the Kyoto Protocol, which makes specific allowances for the inclusion of biological sources and sinks resulting from direct human-induced land-use change and forestry activities. Another example of PCA is an integrated assessment of forests in consideration of ‘cradle-to-grave’ utilization of harvested wood.

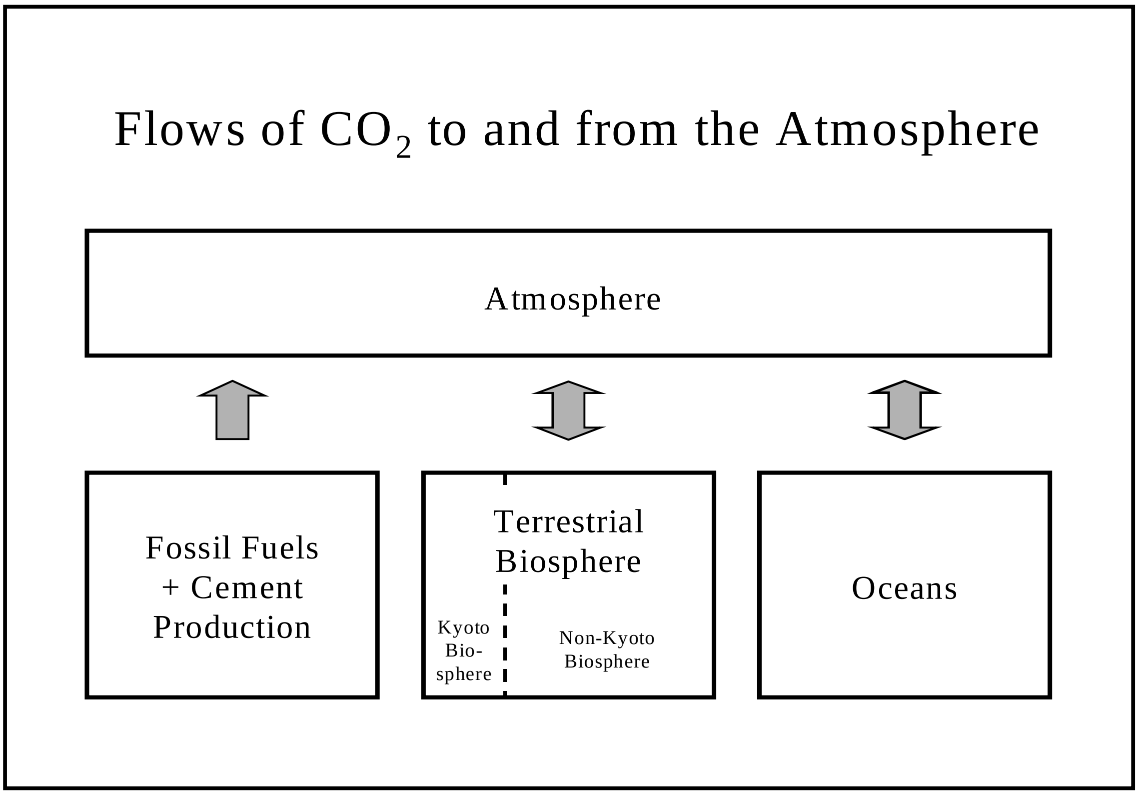


Figure A-1: Carbon exchange between the atmosphere and major carbon reservoirs.

On the contrary, only a few studies exist that are similar to IIASA's Russian carbon study (Nilsson *et al*., 2000) and also strive for national-scale FCA (or full greenhouse gas accounting). Among them are two ongoing studies (Orthofer *et al*., 2000; Jonas, 2001) with focus on Austria and EPA (2000) with focus on the US. Canada and Brazil are reported to be under investigation (Shvidenko, 2000).

The Kyoto Protocol envisages PCA on the national scale, the relevant accounting scale under the Kyoto Protocol.

A.2 Accounting Carbon Temporally

Accounting carbon temporally under the Kyoto Protocol is not uniform. The aggregate anthropogenic CO_2 equivalent emissions (in short: energy and industry emissions) of Annex I Countries must comply with assigned emission limitation or reduction commitments (equivalent to percentages of the base year or period), while land-use change and forestry activities require tracking changes in carbon stocks (and, thus, changes in net emissions; in short: LULUCF emissions) over a period of time. (The latter are included in the Countries' aggregate anthropogenic CO_2 equivalent emissions.)

In principle, these two provisions for accounting carbon have two things in common. Firstly, they require working with emission mean values and secondly, verification. Energy and industry emission mean values are 'compared on the basis of percentages', while the concept of subtracting mean values is proposed for LULUCF emissions. The idea underlying the use of mean values is that, as long as consistent methods are used to account carbon emissions, e.g., in the base year and the commitment year, the potential to introduce biases into the accounting system will be minimized.

Verification means, in principle, verification by independent expert review teams that make sure that the accounting builds upon proper data collection, measurement, and reporting procedures (FCCC, 1998a, b, c; WBGU, 1998; Jonas *et al*., 1999a, b; IPCC, 2000; Tenner, 2000).

- **The concept of 'comparing mean values on the basis of percentages' is proposed for the anthropogenic CO_2 equivalent emissions (energy and industry emissions) of Annex I Countries.**
- **The concept of subtracting mean values is proposed for land-use change and forestry activities (net LULUCF emissions).**
- **Changes in net LULUCF emissions are added to the Countries' energy and industry emissions.**
- **Verification of the Kyoto Protocol is considered to be a technical problem.**

As illustrated in Appendix B, this method of accounting carbon spatially and temporally reveals severe shortcomings. It does not comply with the scientific requirements stipulated by the Kyoto goal.

B What are the Scientific Requirements Stipulated by the Kyoto Goal?

B.1 Spatial Requirements

Climate negotiators want to restrict the Kyoto Protocol to certain parts of the biosphere that are impacted directly by human activity. However, as already pointed out by Jonas *et al*. (1999a, b), separating land directly impacted by human activity from land indirectly affected by human activity may result in carbon accounts that are not only meaningless, but may even lead to false accounting. What happens when a fire starts or a pest breaks out in a sink forest and then spreads to a forest not registered under the treaty? Millions of tonnes of carbon could pour into the atmosphere without anyone getting carbon debits. Therefore, Nilsson *et al.* (2000) conclude that FCA is conditional for all carbon accounting.

Developing this hierarchical aspect of FCA, we can conclude further:

- FCA on the scale of projects within a country does not imply correct carbon accounting on its national scale. And, in turn, FCA on the scale of Annex I Countries does not imply correct carbon accounting on the global scale.

  By 'correct carbon accounting' we mean the correct quantification of net carbon emissions as they would be measured and confirmed by an observer in the atmosphere.
- Only on the global scale can FCA (including all nations) be cross-checked against global atmospheric measurements and biases be detected. (A correction for the ocean-atmosphere interaction can be applied.)

- **FCA is conditional for all carbon accounting.**
- **FCA on smaller spatial scales does not imply correct carbon accounting on larger spatial scales.**
- **A Kyoto Protocol that can be cross-checked must include data from all nations.**

Note that we have used the terms 'correct' and 'cross-check' to describe FCA and its role in the context of the Kyoto Protocol. These terms require further clarification. This brings us to Section B.2, where we introduce 'uncertainty' and 'verification'.

B.2 Temporal Requirements

Temporal requirements are more difficult to specify than spatial requirements. Thus far, uncertainty and verification have only been perceived as technical issues (cf. Appendix A.2), but not yet as fundamental scientific issues. However, the following example illustrates that there is a need to do so. Consider the not unrealistic situation in Figure B-1, which illustrates the crux underlying the Kyoto Protocol: Small (net) emission limitations or reduction objectives on the scale of Annex I Countries face large uncertainties. A dispute around the following three cases is conceivable.

Case 1: A country may succeed in reducing its (aggregate) emissions between time t_1 and time t_2. This reduction may be interpreted, e.g., by applying the concept of subtracting mean values. The uncertainty that is associated with this technique is called trend uncertainty. The trend uncertainty may or may not be greater than a country's quantified emission limit or reduction objective (e.g., Rypdal and Zhang, 2000). Here, let us assume that the Kyoto target of the country falls outside the trend uncertainty. Consequently, the country may be evaluated as not having reached its Kyoto target.

Case 2: The country may dislike this interpretation and argue differently, e.g., by employing the notion of level uncertainties that underly emissions at t_1 and t_2: "The reduction objective falls within the level uncertainty range. Therefore, the conclusion of no-compliance cannot be supported."

Case 3: By way of contrast, a 'physically trained mind' would think in dynamical terms and reject the interpretation of both Case 1 and Case 2. He/she would argue that the emission signal is not verifiable at all at the time point of commitment (Cases 1 and 2 operate within the noise band, i.e., below level uncertainties) but instead, may become verifiable only later.

'Emission signal' means the (absolute) difference in emissions at any two points in time; and 'becoming verifiable' means the Verification Time (VT), i.e., the time required to verify carbon emissions in a dynamic system where both carbon emission rates and their associated level uncertainty are changing over time (Jonas *et al.*, 1999b).

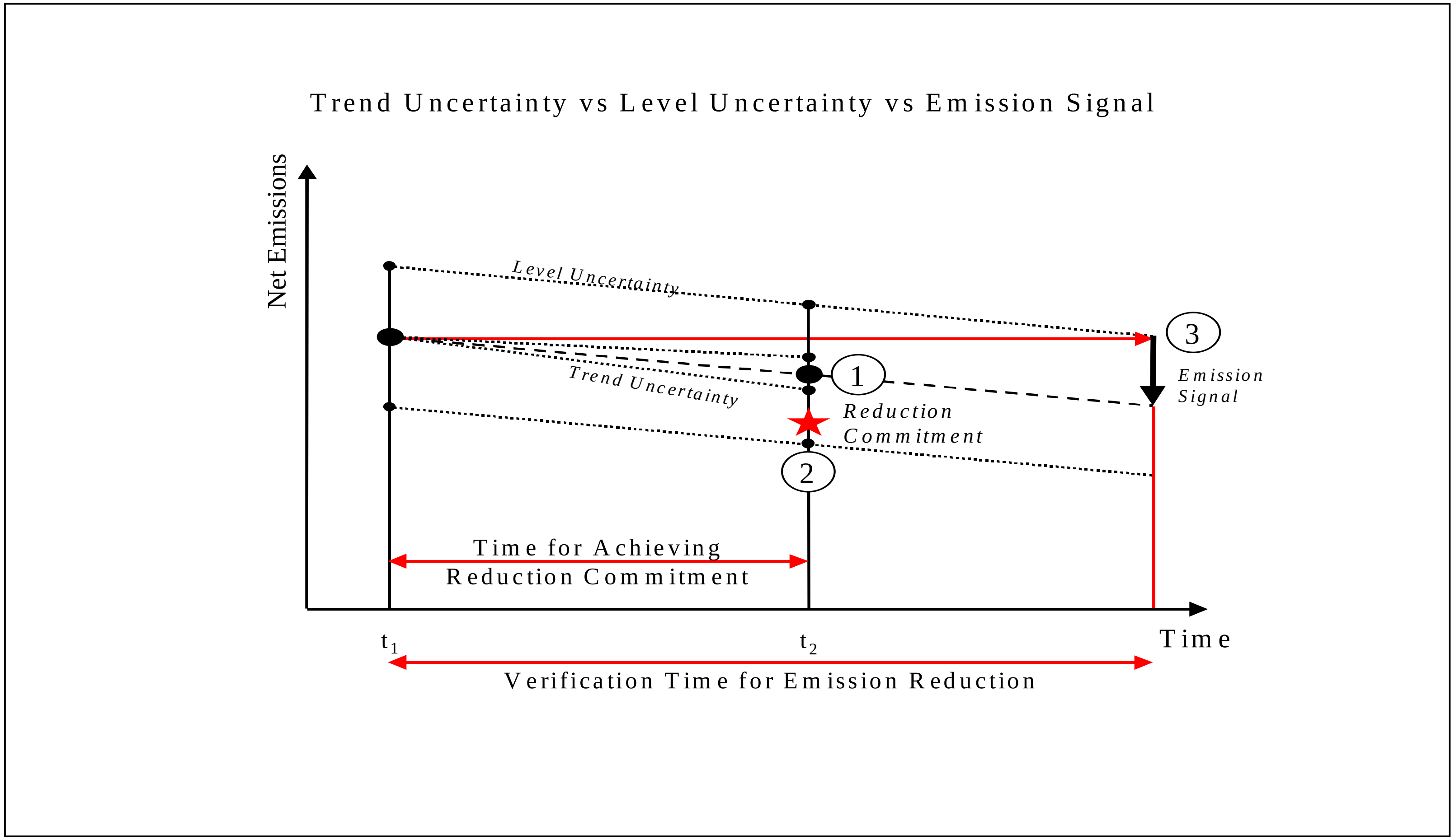


Figure B-1: The crux with the Kyoto Protocol: small (net) emission limitations or reduction objectives on the level of Annex I Countries face large uncertainties. Three conceivable verification examples: verification based on trend uncertainty (Case 1) versus verification based on level uncertainty (Case 2) versus verification based on a physical uncertainty–verification concept (Case 3).

The following conclusions can be drawn:

- The foregoing example illustrates that uncertainty and verification are, first and foremost, fundamental scientific issues. Considering them only as technical issues (cf. Appendix A.2) is inadequate.
- Both uncertainty and verification must be considered under the Kyoto Protocol. Carbon accounting without assessing uncertainty does not allow for understanding verification.
- We are not yet sufficiently knowledgeable to prioritize among the various uncertainty-verification concepts. Here, we only state the following for comparison:

  (i) Specifying the 'comparison of mean values on the basis of percentages' with the help of both trend uncertainty and level uncertainty may lead to interpretational difficulties. The notion of trend uncertainty arises, if this comparison is believed to involve the subtraction of mean values. By way of contrast, the notion of level uncertainty arises, if this comparison is believed to involve the study of simple 'greater-than/smaller-than' relations of one mean value relative to another.

  For instance, by making use of the concept of subtracting mean values, great care must be given to the question of how representative the difference of these values is, in comparison with a country's quantified emission limit or reduction objective. Externalities that affect the mean values, such as world oil prices, 'local' climate, etc., may be substantial and easily lead to misinterpretations of mean value differences. Their comparison with small quantified emission limitations or reduction objectives (or emission reductions as a result of policy measures) may be meaningless.

  Similar interpretational difficulties arise when level uncertainties (which are not expected to be negligible) are compared with small quantified emission limitations or reduction objectives (or emission reductions as a result of policy measures).

  (ii) Dealing with uncertainty and verification in a continuous fashion, i.e., not at only two specified points in time (base year and commitment year) as envisaged under the Kyoto Protocol and reflected in Figure B-1, seeks to grasp the emission (or change in emission) signal more fundamentally (as well as its underlying uncertainty). Such a physical-based verification concept that has been generalized to grasp uncertainty and verification dynamically over time is believed to provide a more adequate basis for dealing with the uncertainty–verification issue.

  For instance, consider the event, where a country's Kyoto target is only slightly lower than its base year emissions. The country may succeed in reaching its Kyoto target in two steps, initially by a steep increase followed by a steep decrease. This path reveals strong emission signals that outstrip uncertainty within a very short time period, while this is not so when uncertainties are only assessed at the start (base year) and end point (commitment year) in time (as done in Figure B-1).

  However, we are only at the beginning of understanding this physical-based verification concept.

  For instance, it commands an answer to the non-trivial question: What is the 'appropriate' temporal emission mean value of a country and how does it develop over time (as well as its uncertainty)? Another question that needs to be examined is: can this concept deal with nonlinear uncertainty-verification behavior, if it is extended to reflect the dynamics of emissions higher than first order?

- **Uncertainty and verification are, first and foremost, fundamental scientific issues.**
- **Both uncertainty and verification must be considered under the Kyoto Protocol. Any accounting without assessing uncertainty does not allow for understanding verification.**
- **We are not yet sufficiently knowledgeable to prioritize among the various uncertainty-verification concepts.**
- **The use of trend uncertainty and level uncertainty may lead to interpretational difficulties.**
- **A physical-based verification concept that has been generalized to grasp uncertainty and verification dynamically over time is believed to provide a more adequate basis for dealing with the uncertainty–verification issue. However, we are only at the beginning of understanding this concept.**

B.3 Combining the Spatial and Temporal Requirements

Irrespective of which concept is considered adequate in dealing with the uncertainty–verification issue, further conclusions can be drawn by putting uncertainty and verification into the context of FCA, including FCA across spatial scales:

- Whether or not FCA implies verifiability (i.e., verifiability within the first commitment period) depends on the uncertainty–verification concept selected.
- Verifiable carbon accounting on the scale of projects within a country does not imply verifiable carbon accounting on its national scale. And, in turn, verifiable carbon accounting on the scale of Annex I Countries does not imply verifiable carbon accounting on the global scale.
- Bottom up–top down verification on the global scale — by way of full accounting for fossil fuel, terrestrial biospheric and oceanic CO_2 sources and sinks and cross-checking them against atmsopheric CO_2 measurements — is **the** ultimate form of verification. This global-scale verification is superior to temporal verification on sub-global scales.

  The first is necessary and sufficient to detect biases, the latter is not. (Note that temporal verification on sub-global scales can also experience bottom up–top down verification on sub-global scales, e.g., by measurements that overlap each other spatially. However, it is not unrealistic to assume that such cross-checks on sub-global scales will be the exception and not the rule. Therefore, they are not discussed here further.)

- **Whether or not FCA implies verifiability depends on the uncertainty–verification concept selected.**
- **Verifiability on smaller spatial scales does not imply verifiability on larger spatial scales.**
- **Global-scale verification (bottom-up versus top-down) is superior to temporal verification on sub-global scales.**

Acronyms, Definitions and Nomenclature

COP 6	Sixth meeting of the Conference of the Parties (The Hague, Netherlands; 13–24 November 2000)
FCA	full carbon accounting When using this term in the context of the Kyoto Protocol, we tacitly refer to 'terrestrial full carbon accounting', that is, the atmosphere–fossil fuel–terrestrial biosphere system where the atmosphere is adjusted for the oceanic system. FCA, in addition to the fossil fuel system, encompasses and integrates all (carbon-related) components of all terrestrial ecosystems and is applied continuously over time (past, present, future). We assume that the components can be described by adopting the concept of pools (also termed reservoirs or stocks) and fluxes (also termed flows) to capture their functioning. The carbon pools may be undisturbed (at least theoretically), impacted directly or indirectly by human activity, and linked internally or externally by the exchange of carbon, as well as other matter and energy (cf. Steffen *et al.*, 1998; Jonas *et al.*, 1999a, b; Nilsson *et al.*, 2000). The fossil fuel system is defined in accordance with Annex A of the Kyoto Protocol (FCCC, 1998a), i.e., to include the emission sectors/source categories (1) energy, (2) industrial processes, (3) solvent and other product use, (4) agriculture, and (5) waste; or briefly as 'energy + industry', letting the source/sink category 'land use, land-use change, and forestry (LULUCF)' (see below) fall under the terrestrial biospheric system. So far, the term FCA is still used and applied ambiguously by scientists.
FCCC	Framework Convention on Climate Change
GHG	greenhouse gas
Kyoto biosphere	encompasses that part of the biosphere where land use-change and forestry activities as specified by Articles 3.3 and 3.4 of the Kyoto Protocol take place.
LULUCF	land use, land-use change, and forestry
non-Kyoto biosphere	represents the complement to the 'Kyoto biosphere'. For any given region the areas of the Kyoto biosphere and non-Kyoto biosphere add up to the area of the total biosphere.
PCA	partial carbon accounting PCA is applied, e.g., under the Kyoto Protocol, which makes specific allowances for the inclusion of biological sources and sinks resulting from direct human-induced land-use change and forestry activities.

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