Uncertainties of the regional terrestrial biota Full Carbon Account: A systems analysis

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Abstract

We discuss the background and methods for estimating uncertainty in establishing a regional, terrestrial biota Full Carbon Account (FCA) in a holistic manner utilizing our experiences in generating such an account for a vast region in Northern Eurasia. For such an analysis, it is important to (1) provide a *full* account; (2) consider the relevance of a *certified* account; (3) understand that any FCA is a fuzzy system; as well as (4) understanding that a comprehensive assessment of uncertainties requires combining system constraints to the methodology and structure of the FCA. We believe that at the current level of knowledge and available information a certified FCA for large regions of the Northern hemisphere could be realized for present and recent periods.

1 Introduction

Recent steps of post-Kyoto developments have led to the understanding that only a Full Carbon Account (itself and as an information and methodological nuclei of the Full Greenhouse Gas Account) corresponds to the ultimate goals of the United Nation Framework Convention on Climate Change [18, 25]. The Kyoto Protocol and recent documents of IPCC still consider Partial Carbon Accounting Systems, although it can be anticipated that the transition to full accounting will eventually be put on the climate change science agenda in the near future.

The Full Carbon Account includes two parts that differ by nature and methodology: assessing emissions caused by the antroposphere (industry, energy, etc.) and quantifying interactions of terrestrial vegetation with other components of the biosphere, in particular, with the atmosphere. The share of emissions of these two components in summarized fluxes of the FCA at the national level may be of the same magnitude (e.g., for Russia, [21]). Experiences of some countries (Austria, Finland, Norway, The Netherlands, the UK and the USA) show that the uncertainties of CO_2 emissions from fuel combustion are low, in limits of ± 2–4% (confidential probability 0.95). In spite of the uncertainties in other gases that are far higher (e.g., in range from about ±17 to -48% for CH_4 emissions) [15, 24], the overall uncertainties (e.g., expressed as uncertainties in the Global Warming Potential) of the industry sectors are substantially less than uncertainties of fluxes resulting from the functioning of terrestrial vegetation [18]. It means that the eventual uncertainties of the Full Carbon Account mainly depend on the uncertainties generated by the biosphere, and the latter should be a subject of a special analysis.

The Kyoto Protocol and following documents [9,10,11] mention uncertainty, but it does not put these at the center of the problem (e.g., 19, 20]). The required reliability level of the Full Carbon Account, which should be provided at regional and global levels, is still a subject of discussion. For the partial account, which is defined by the Kyoto Protocol and subsequent international documents, industrial countries have a greenhouse gas emission reduction target of 5.2% and the European Union of 8% below the 1990 level by the first commitment period 2008–2012. It means that the uncertainties for the Full Carbon Account should be minimized to at least a level which is able to provide a reliable identification of this reduction. Some scientific discussions (e.g., in the framework of the Global Carbon Project) presumably indicate required limits of uncertainties for summarized continental carbon fluxes caused by terrestrial vegetation at a level of ±20-25%; evidently it seems to be too high if the Full Carbon Account were to become a subject of the post-Kyoto negotiation process. Our tentative results for temperate and boreal regions show that uncertainties of the FCA for large regions could be decreased to a level of 4–5% (confidential probability 0.9) if the FCA meets a number of system requirements.

There are two major goals of the full carbon account which are equally important and interdependent: (1) quantifying all carbon pools and fluxes included in the account; and (2) reliably estimating uncertainties. The logic of recent post-Kyoto developments implies the need for moving towards a certified full carbon account. A *certified account* means that: 1) uncertainties at all stages and for all modules of the accounting scheme are estimated in a comprehensive, transparent and verifiable way; and 2) the methodology of the FCA should function as a guideline for how uncertainties can be managed, in particular, if the results of the accounting do not satisfy required uncertainty levels. This problem is far from trivial. The Global Carbon Project [4] indicates, among inherent shortcomings in grasping the carbon budget, that (1) existing global models are unable to determine carbon sources or sinks with acceptable accuracy at the regional and continental level or the interannual time scale, (2) there are no agreements between top-down and bottom-up approaches, (3) there are substantial inconsistencies between global and regional budgets, (4) temporal patterns are poorly understood at time scales greater than a few years, and (5) there are big gaps in comprehending the spatial and temporal pattern of human-induced fluxes, etc.

This paper presents a brief analysis of experiences and lessons that resulted from assessing uncertainties of the terrestrial biota full carbon account (below – FCA) at the regional scale for a large region of Siberia through an EU-funded project entitled "SIBERIA-II" (Multi-sensor Concepts for Greenhouse Gas Accounting of Northern Eurasia), as well as from the full carbon account of the entire Russian territory carried out by IIASA's Forestry Program during recent years. We attempt to illustrate the fact that only a consecutive holistic approach is able to serve as the background for a certified FCA, and briefly analyze systems requirements of its structure and methodology.

The terminology used below is generally accepted in statistical theories and risk analysis. Conventional terms for standard statistical analysis are: (1) *accuracy* as correctness or a measure of the systematic error (bias) [accuracy addresses errors made in measuring within the precision of the measurement capability to discriminate]; (2) *precision* as reproducibility or a measure of the random error; it deals with our inability to discriminate among values within a parameter, it is imprecision; (3) a (rough) *mistake* is a measurement that is known to be incorrect due to carelessness, accident or the ineptitude of the experimenter. In a FCA, direct use of these terms is usually limited to relatively simple statistical tasks, which are mostly based on direct measurements.

The mathematical theory distinguishes between *uncertainty* and *variability*. Albeit the term *uncertainty* is used in different meanings: statistical variability, lack of knowledge, lack of confidence in a single value [6, 7, 8], the use of this term in global change science is rather consistent. "Uncertainty" is understood as a description of the imperfection in knowledge of the true value of a particular parameter or its real variability in an individual or a group. In essence, uncertainty is the absence of information; or is an expression of the degree to which a value is unknown [12, 23]. Uncertainty can be represented by quantitative measures (e.g., a range of values calculated by various models) or by qualitative statements (e.g., reflecting the judgment of a team of experts). *Variability* is a special contributor to uncertainty. "Inter-individual variability" means the real variation among individuals, in exposures, or the parameters. In general, uncertainty is reducible by collecting additional data or by using better models, whereas real variability cannot be changed as a result of better or more extensive measurements (however the latter can improve the quality of estimates used). In our analysis we defined *uncertainty* as an aggregation of insufficiencies of our system output, regardless of whether these insufficiencies result from a lack of knowledge, the intricacies of the system, or other causes [18]. Finally, uncertainties in the FCA could be expressed in terms either confidential intervals of probability distribution functions.

2 Uncertainties of the regional full carbon account

Strictly speaking the "ideal" FCA should be a result of the continuous monitoring of terrestrial biota in space and time. Recent developments allow us to conclude that some simplified patterns of such an approach could be realized in the future. Currently, all carbon accounting schemes are forced to use many heterogeneous information sources including results from different measurements, assessments, as well as expert estimates over time. It generates numerous and diverse uncertainties. Taking into account specifics of carbon account, different classifications (decomposing, categorizing) of uncertainties can be relevant. For the IPCC TAR Assessment, Moss and Schneider [17] considered four major groups dealing with (1) confidence in the theory, (2) measurements, (3) models, and (4) consensus within a discipline. Rowe [23] considering common aspects of risk analysis divided uncertainties into temporal (past and future), structural (complexity), metrical (measurements), and translational (explaining uncertain results). For categorizing the FCA a more detailed classification in the following groups seems relevant (see also [13, 18, 26]).

1) *Definitions and classification schemes* used in calculations. As a rule, the definitions and classification schemes currently used in the FCA have been introduced for purposes other than carbon accounting, and often correspond to inappropriate and obsolete standards and measuring technologies.

2) *Shortcomings of available data.* Some important data have never been and are not measured, which leads to incomplete and sometimes inappropriate substitutions.

3) *Unknown or insufficient precision of measured data.* Reasons for this could vary: subjective (not random) sampling; biased statistics; deliberate falsification; inappropriate measurement techniques; etc.).

4) *Lack of a proper basis for upscaling.* Very often, there is no solid platform for estimating the accuracy of upscaled point measurements, gradients are unknown and stratification is provided based on expert judgments.

5) *Short time series.* Some processes require historical reconstruction for up to 150–200 years which is not covered by existing historical records.

6) *Lack of knowledge of some important processes.* For instance, the post-disturbance processes in soil on permafrost, or nitrogen turnover after biotic disturbances are to a significant extent a "black box".

7) *Oversimplification of the modeling approach.* In both major methodological approaches of carbon account, i.e., pool-based and flux-based carbon account, the regional FCB is presented by a sophisticated superimposition of (almost exclusively) non-stationary stochastic processes. Still there is no methodology which would use this intrinsic feature of a FCB as a prerequisite for its modeling and quantification, and the substitution of stochastic processes with deterministic models is usual. There are many other examples of this type.

8) *Spatially and/or temporarily insufficient observing systems.* Significant remote areas (e.g., in the Russian north) are not covered by either remote sensing or on-ground observations. Some indicators are very dynamic, and existing monitoring systems and available data cannot grasp this dynamics, e.g., seasonal dynamics of insect outbreaks in boreal forests.

Although each class of uncertainties can be addressed separately, they are not necessarily independent, and their interdependence should be examined. The above list of uncertainty sources can be applied to some or all periods of the assessment: past, present and future. However, any prediction and forecast includes the need to consider many other uncertainties dealing with future drivers (climatic, ecological, social and economic), and responses and feedbacks of terrestrial ecosystems. The possible level of background uncertainties could be illustrated by the uncertainties of climatic predictions. Using 12 three-dimensional general circulation models (GCMs), including seasonal cycles, a mixed layer ocean and interactive clouds and other features, the projected increase in global mean surface air temperature under equilibrium conditions for doubled CO_2 concentrations in the atmosphere varies approximately three-fold (from 1.6 to 5.4°C, mean 3.82, coefficient of variation 26.3%) [2]. We do not consider this special (and highly uncertain) case of predicting modeling in this analysis.

As it follows from the above analysis, any FCA is a typical *fuzzy* system. We use this term in its usual mathematical sense [14, 29] bearing in mind that many elements of the FCB (components and stages of the FCA) present not a crisp set, but require the knowledge of multi-valued membership functions. In essence, albeit "fuzzy logic is part of a formal mathematical theory for the representation of uncertain systems" [3], the comprehensive formal use of this theory, which would deliver meaningful results, is a matter of the future. Although fuzzy logic and fuzzy methods are recommended as a mean to incorporate subjective information in different aspects of assessing uncertainties (e.g., [4,5]), their applications are limited by some partial tasks. In the framework of FCA, it is productive to apply "fuzzy thinking", a philosophical approach, which helps much in structuring problems and developing a relevant FCA system. During the last years, this philosophy has also been applied to a "multiple-constraint" approach, where heterogeneous data – measurements of fluxes, remote sensing data, data of different inventories, etc. – provide constraints in models used and assessing results (e.g., [29]).

"Fuzzy thinking" leads to an important conclusion which defines a relevant specific methodology of the certified FCA: any individual method or model of the FCA applied separately is unable to provide a sufficient estimation of uncertainties. It defines the need to systematically integrate relevant methods and models. It leads to the philosophy of *integration* in all its ramifications. For the FCA, the solution is an integration of all relevant information sources (on-ground, remote sensing data and appropriate regional ecological models), soft and hard knowledge. On the other hand, integration should be provided for different components of the FCA: carbon of terrestrial biota, ocean and atmosphere. A consistent global carbon budget is an indicator of its reliability. Comparing the results received by different methods is an important part of verification.

An additional dimension of uncertainties is generated by the requirement of having *a full* carbon account. By definition, "a full C budget encompasses all components of all ecosystems and is applied continuously in time" [28]. However, in spite of progress over the last decade, there remain substantial uncertainties in understanding regional and global carbon budgets. This permits estimating the completeness of the FCA in an expert way only[1]. The judgment on a completeness of estimating FCB continuously in time can be also satisfied in a very approximate manner. Because the FCB has a "memory", up-to-date estimates of C fluxes may strongly depend upon the previous, sometimes long periods for which relevant measurements may not be provided, and required information simply does not exist. In addition, the completeness greatly depends upon the end-point user target. For example, the final goal of carbon accounts can be defined either as an assessment of the amount of C-CO_2 in the exchange, or quantities of all carbon contained gases, or the Global Warming Potential. Nevertheless, experiences of the FCA for some countries show that about 96–98% of recognized carbon fluxes are usually included in the consideration, although in essence this conclusion is an expert estimate [18]. The completeness allows us to implement balance estimating and analysis of consistency of individual modules and blocks of the FCA (which is not possible for any Partial Accounting Systems). This presents additional approaches for estimating (final) uncertainties of the accounting systems, as well as for understanding the specifics of partial accounting systems.

3 Requirements to the Terrestrial Biota Regional Full Carbon Account (FCA)

The next most important requirements to any certified FCA result from the above considerations.

1. Only a system (holistic) approach (with modifications resulting from the fuzziness of the FCA) can serve as a methodological background of the FCA. From a substantial point of view, implementation of the landscape-ecosystem methodology is one of only a few possibilities for a consecutive system analysis. The landscape-ecosystem approach postulates that an ecosystem (i.e., vegetation-soil ensemble of different scale) is considered as a primary unit of scientific description, modeling and interpretation, and the quantification of intra-

[1] We distinguish between a full carbon budget (FCB) as a natural system, and a full carbon account (FCA) as an artificial accounting system.

ecosystem processes of energy and matter exchange should include the impacts of properties of an individual landscape.

2. Use of strict and mono-semantic definitions and formally complete classification schemes.
3. Explicit structuring of the account; use of strict intra-system (module) spatial, temporal and process boundaries.
4. Estimation of uncertainties should be provided at all stages and for all modules of the FCA. In particular it allows gaining additional information needed for understanding relevant ways for the management of uncertainties.
5. Accounting schemes, models, and assumptions should be presented in an explicit algorithmic form. It means that the use of soft knowledge (e.g., in the form of expert estimates), which is inevitable in the FCA, should be provided in a "quantified" form and by methods which would allow to minimize possible biases of subjective information.
6. The accounting scheme should provide a spatially explicit distribution of considered pools and fluxes. It means that all major components of the FCA should be georeferenced at relevant scales.
7. Temporal dimensions of the FCA (a year or a period of accounting) should be clearly identified.

4 Assessing uncertainties

Two main statistical concepts – the probability density function and confidence limits – are normally used for assessing uncertainties. The IPCC Guidance suggests the use of a 95% confidence interval. Taking into account the specifics of the FCA, there is some basis to weaken this traditional recommendation, and the confidential probability of 0.9 seems more relevant.

We examined the following way for assessing the uncertainties of the FCA: (1) estimation of precision of all intermediate and final results; (2) "transformation" of precision in uncertainty; and (3) multiple-constraint comparisons of results.

Estimation of precision. The FCA is presented as a hierarchical structure of analytical expressions. It allows the formal use of the error propagation theory assuming that distributions of variables used in the calculations more or less correspond to normal frequency distribution. However, only some of the initial data result from direct measurements for which standard errors, probability distribution functions, etc., can be estimated with conventional statistical methods. This generates some peculiarities: (1) the need to use estimates of precision of initial variables "by analogy" (i.e., average values by classes of the classification used), or based on expert estimates and subjective probabilities, and (2) the use of "summarized errors" as a substitute of random errors. As a rule, it is impossible to divide random and systematic errors of initial variables used in the FCA. Thus, summarized errors are considered as some functions of random and systematic errors. In practical situations, the share of biases is relatively small (in limits of 10–15% of the random error). In such cases, applications of the error propagation theory do not change the essence of statistical conclusions.

"Transformation" of precision in uncertainties. The calculated precision is transformed into uncertainty based on sensitivity analysis and expert estimates of unaccounted impacts and processes. The Monte Carlo method is often used as a tool for sensitivity analysis. Details of this procedure depend upon the end-point target of the assessment. (1) The endpoint is a fixed but unknown value (e.g., Net Biome Production). Values are sampled at random from distributions representing various "degrees of belief" about the unknown "fixed" values of the parameters (i.e., the true but unknown value is equal to or less than any value selected from distribution). The subjective confidence statement about the true but unknown assessment end point accounts for multiple sources of uncertainties (inventory or model structure; presence, variability, and representatives of data; quantified expert opinions, etc.). Uncertainty about a quantity that is fixed (or deterministic) with respect to the assessment end point is often called Type B uncertainty. Variation of input data allows the selection of "important input parameters" which contribute most to the spread in the distribution of the FCA results. (2) The end point is an unknown distribution of values. In such a case, the Monte Carlo simulations are performed in two dimensions producing numerous alternative representations of the true but unknown distributions (assessment of uncertainty of Type A). In practical applications of the FCA, both of the above procedures are used, however it often occurs that a mixture of both types of uncertainties is present.

Although Monte Carlo calculations are not free from some subjective elements (e.g., a "selection" of the type of the unknown distribution), this method presents both comprehensive information about uncertainties of the accounting scheme (model) and important information for management of uncertainties. These results often serve as an iterative step in a process to improve model estimates.

However, we have to note that all of these results are "true" only inside of the approach (model) used, under given inputs and assumptions, and can have little in common with reality, if the model or assumptions are not "comprehensive" or oversimplified. Thus, if, e.g., model FORCARB (carbon inventory for 2000 for private timberland of USA, which covers about 75% of the country's productive forests) estimates uncertainty ±9% of the estimated median of the total carbon in the year 2000 and ±11% in the projection year 2040 [7] – this is only an information that Monte Carlo calculations have presented these results using the above model (which is rather simple). It explains the need for independent analysis of the completeness of a FCA that is used. One way to provide this analysis is by using experts' judgments on the topic; these judgments are quantified and embedded (in addition to Monte Carlo or other methods of sensitivity analysis) into final values of uncertainties [27].

Multiply-constraint comparison of results. The balance and consistency analysis of carbon budgets of relatively closed blocks (modules) of the FCA, comparisons of independently calculated intermediate results and multi-constraints analysis of final results – three important techniques, which allow us to make a final judgment about the FCA. We have to point out the crucial importance of the multiply-constraint methodology. The "top-down – bottom-up" analysis is currently a major tool for understanding the global carbon budget (see Jonas and Nilsson, this issue). It could be very useful at continental and other macro-regional FCAs. Hence, the FCA for Russia showed that the former intensively debated problem of the missing sink is a result of the incompleteness of the account [25].

5 Some practical implementations and results from case studies

We attempted to introduce the above requirements and techniques in estimating the FCA for a large (~3 million km^2) region of Northern Eurasia, which stretches roughly 3000 km from the north to the south and includes almost all diversity of bio-climatic zones and landscapes of the Northern hemisphere. The methodology of the project is based on an integration of pool-based and flux-based approaches. The latter is expressed as assessing fluxes (expressed in units of carbon per unit of time) at boundaries of terrestrial ecosystems with other components of the biosphere (atmosphere, lithosphere, hydrosphere)

$$NBP = NPP - HSR - DEC - D - TL - TH,$$

where NBP and NPP are net Biome and Net Primary Production, HSR – heterotrophic soil respiration, DEC – flux due to decomposition of coarse woody debris, D – flux due to disturbances, TL and TH – fluxes to lithosphere and hydrosphere. The pool-based method estimates carbon pools at the beginning and end of the assessment period. A combination of these two results allows us to estimate the methodological consistency of the FCA. From a modeling point of view, the FCA consecutively examines three approaches: (1) "base-line" inventory, assessing average values, (2) introduction of the latter environmental indicators by using empirical and semi-empirical ecosystem and landscape models, (3) use of process-based blocks as part of the multiple-constraints procedure. The information base has been developed in the form of an Integrated Land Information System (ILIS) which comprises multi-layer GIS and corresponding attributive databases. All relevant information sources have been used for the development of the ILIS: available maps and legends; data of different inventories (in particular, forest inventory) and surveys; various scientific archives; official statistical data; etc. A multi-sensor remote sensing (RS) concept was introduced. Information presented by RS (about 20 different sensors were examined) was of crucial importance considering the large scale and remoteness of the region. However, many inconsistencies in the technical capacities of RS sensors, spatial and temporal resolution and needs of the FCA have been recognized. The objective in using diverse information was to increase the synergy from combining various, relevant information sources. The approach presented the possibility of independent estimates of many components of the FCA.

The approach outlined above allowed the development of a GIS-layer "relevant for the FCA" and corresponding DB. The cartographic part of the layer is presented by about 25,000 georeferenced ecosystem-based polygons (i.e., polygons serve as a primary ecosystem-landscape unit) which are combined in 25 relatively homogeneous ecological regions. The FCA is provided for each of the polygons and is aggregated by ecoregions. Part of the components of the FCA is estimated based on regional ecosystem-landscape models. It puts special requirements on the hierarchical structure of the classification of land classes used in order to limit the variability of the FCA components within the classes.

The FCA and the assessment of uncertainties for the entire region have not been finished yet. However, some preliminary conclusions can be made. (1) There is no doubt about the usefulness of an ecosystem-landscape approach as the scientific background for the FCA. (2) Vegetation components of the FCA for individual polygons are estimated with rather high reliability. Hence, live biomass (phytomass) by polygons is defined with uncertainties ± 7–15%, Net Primary Production and Heterotrophic Soil Respiration ± 15–20% (confidential probability here and below 0.9). However, it has required the development of a number of special regional modeling systems based on a substantial amount of sample plots (more than 1000 for each component) and the use of all available reference and normative information (yield tables, models of gross and net growth, etc.). (3) Uncertainty of estimates of soil carbon pools are higher (in range of ± 20–25%) due to the rough resolution of soil data (the basic soil map and reference DBs are presented at scale 1:1Million) and insufficiently documented history of vegetation fire during the two recent decades. However, at the ecoregional level uncertainties of major pool and fluxes (like NPP, HR) are estimated to be in the range of 1–3% (each ecoregion contains 600 to 1500 polygons), under the assumption that the account has no significant biases. Tentative calculations provided for a number of ecoregions by both pool-based and flux-based methods showed rather consistent results, although assessing the soil carbon dynamic is substantially less certain than for other carbon pools (phytomass, CWD). (4) Some problems with estimating uncertainties are generated by aggregation ecosystems in polygons taking into account the rough scale of the accounting. To some extent these uncertainties are decreased by the implementation of “mixed classes” (e.g., polygons, which contain more than one class). On the other hand, implementation of “virtual polygons” presents the additional possibility to decrease uncertainties of this type. “Virtual polygons” comprises land classes, which are represented by numerous plots of small areas and are not individually indicated at the GIS layer (roads, small rivers and water reservoirs, etc). As a rule, the total area of such land classes could be received from independent sources, and corresponding corrections of an area are provided at the ecoregional level. However, the aggregation is substantially based on professional judgments, and estimating these uncertainties substantially includes expert components. (5) Interannual variability of the FCA could be very high (up to 2–3 fold for NBP during a 10–15 year period) and is defined by the impacts of seasonal weather specifics and by the extent and severity of disturbances. (6) Uncertainties of the FCA estimated for an individual year could be very high. Thus, considering time series is the best strategy for reducing uncertainty.

There is additional information on possible ways to manage uncertainties. There are many ways to evaluate the value of information, and most of them rely on determining the benefit of making a decision based on current knowledge versus spending more resources to improve the knowledge base that could be used in Bayesian decision analysis (Berger 1985), or by referring to the more familiar expected value of perfect information (Morgan and Henrion 1990). Effective ways of reducing carbon flux uncertainties strictly depends on the structure and specifics of the accounting schemes, and the most relevant ways to reduce their uncertainties differ from those required to reduce uncertainties in inventorying carbon pools. As a rule, an optimal way to reduce uncertainty requires a systems approach and lies in the attempt to utilize the synergism of combining heterogeneous information sources. For example, to substantially reduce the uncertainties of emissions caused by vegetation fires require their appropriate classification (types of fires, types of combustibles, etc.), fuel maps, new or modified RS sensors, which enables identifying types of fire and their severity, and improved empirical models (e.g., to assess the amount of consumed combustibles of definite forest types depending on environmental indicators, fuel storage, etc.). Sometimes it is necessary to keep in mind that some uncertainties cannot be reduced given current knowledge and economic conditions.

6 Conclusion

The development of integrated observing systems seems to be a major strategic idea to establish certified regional terrestrial biota full carbon accounts in the future. The integrated observing system is understood as a permanent tool to combine all relevant information sources (on-ground measurements, remotely sensed data and empirical knowledge) and models of different types linked to primary polygons relevant for the FCA. Some prototypes of elements of such systems and possible decisions are outlined above. However, any proper development and implementation of such a system will require substantial improvements of all its elements and subsystems. In the foreseeable future, the FCA will remain a fuzzy system. It means that judgments about the reliability of the FCA will be based on a combination of strict formal methods, as well as expert conclusions. If the Kyoto Protocol will enter into force, the technical task of assessing uncertainties will gain political and economic importance. This will require substantial improvements in the theoretical and practical aspects of the problem, as well as the development of special institutions, which would be responsible for certifying FCAs.

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