Greenhouse gas emission uncertainty in compliance proving and emission trading

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Abstract

A solution for compliance proving and emission trading in case of big uncertainties in emission observations is proposed. It is based on the undershooting concept, from which both mathematical conditions for proving the compliance with a risk α, and for calculation of effective emissions for trading is obtained. This notions are used for defining effective permits, which can be traded on a normal basis, neglecting the underlying uncertainty.

1 Introduction

Uncertainty in the greenhouse gas (GHG) inventories has been estimated to be in the range 5-20%, depending on the scope and methodology used [9], [5]. Even if some of the computations need unification of assumptions and possibly recalculation, the uncertainty is still believed to be about 10-12% or more for most countries [11] and therefore is larger than the reduction commitments. Thus, the uncertainty seems to become a big problem both in the compliance proving and in implementation of the flexible mechanisms: emission trading, joint implementation and clean development mechanism.

Uncertainty varies between parties taking part in the Kyoto agreement. They also vary considerably between different emission activities. Having this in mind one can think of better or poorer quality inventories or more or less credible reduction of the GHG emissions. When dealing with the flexible mechanisms, better or poorer quality goods are offered for sale or exchange. Should they be treated on the equal basis? Without explicit rules of maintaining this problem it is rather doubtful that it will be solved by the market itself. And leaving this problem unsolved may undermine credibility of the whole reduction process, as, in principle, one can always report bigger savings in emissions with increased uncertainty.

This problem found rather inadequate attention in the literature. Assessments of uncertainty were done and compared for several countries, see e. g. [9], [3], [4]. Some as far vague considerations on excluding most uncertain activities from the emission trading were mentioned [10], [5]. In [1], [2] undershooting as the basis for proving compliance was proposed. Also the argumentation in this paper uses undershooting concept as far as the compliance proving is concerned. We introduce, however, a risk that the real emission may not satisfy the reduction obligation due to big uncertainty in inventories. This allows us to treat in a similar way uncertainty of different types, like interval or stochastic one. We also consider uncertainty in both the commitment and the basic years as contributing to the overall uncertainty when comparing the involved emission reduction. To avoid big changes in the reduction level connected with undershooting we propose to appropriately adjust (shift) the reference obligation levels.

The compliance proving rule proposed in the paper is further a starting point for reevaluation of the traded units of emissions, taking into account the different underlying uncertainty. This is done by assuming that the uncertainty of the traded emissions contributes to the buyer's overall uncertainty. Big uncertainty in the sold emissions increases the uncertainty of the buyer's emission balance and therefore must be of smaller worth to the buyer.

This idea is transfered to definition of an emission permit in case of uncertainty. The new (effective) emission permit includes uncertainty in the way that a party with big uncertainty of the inventory is allocated less emission permits than another party with the same emission and smaller uncertainty. The effective permits are subject to normal trading, as in the case of permits with exact knowledge of emissions.

A preliminary proposition of the above solution was presented at the workshop held in IIASA [7]. A more elaborated paper was presented at a conference in Poland [8]. A simplified presentation can be also found in the IIASA Interim Report [3].

2 Notation and problem formulation

By $x(t)$ we denote the real, unknown emission of a party in the year t. It can be only estimated, basically through emission inventory. Let $\hat{x}(t)$ denote the best available estimate of $x(t)$. This estimate is subject to estimation error connected with the inventory uncertainty. Mainly interval type uncertainty will be discussed here, while stochastic type will be only presented in a limited scope.

By δ we denote the fraction of the party emission that is to be reduced in the commitment year(s) according to obligation. The value of δ may be negative for parties, which were alloted limitation of the emission increase. Denoting by t_b the basic year and by t_c the commitment year the following inequality should be satisfied to prove the compliance

$$x(t_c) - (1 - \delta)x(t_b) \leq 0 \tag{1}$$

The problem arises because neither $x(t_c)$ nor $x(t_b)$ are known precisely enough. Instead, only the difference of estimates can be calculated

$$\hat{x}(t_c) - (1 - \delta)\hat{x}(t_b)$$

where both $\hat{x}(t_c)$ and $\hat{x}(t_b)$ are known with intolerable low accuracy.

3 Compliance proving

Interval type uncertainty. Assuming that the uncertainty intervals at the basic and the commitment years are $\pm\Delta_b$ and $\pm\Delta_c$, respectively, we have

$$x(t_b) \in [\hat{x}(t_b) - \Delta_b, \hat{x}(t_b) + \Delta_b], \qquad x(t_c) \in [\hat{x}(t_c) - \Delta_c, \hat{x}(t_c) + \Delta_c]$$

from where, using the interval calculus rules, we get

$$x(t_c) - (1-\delta)x(t_b) \in [D\hat{x} - \Delta_{bc}, D\hat{x} + \Delta_{bc}]$$

where $D\hat{x} = \hat{x}(t_c) - (1-\delta)\hat{x}(t_b)$ and $\Delta_{bc} = \Delta_c + (1-\delta)\Delta_b$.

To be fully credible, that is to be sure that (1) is satisfied even in the worst case, the party should prove $D\hat{x} + \Delta_{bc} \leq 0$, see Fig. 1. We say that the party *proves the compliance with risk* α if $D\hat{x} + \Delta_{bc} \leq 2\alpha\Delta_{bc}$, see Fig. 1 for the geometrical interpretation. After simple algebraic manipulations this gives the condition

$$\hat{x}(t_c) \leq (1-\delta)\hat{x}(t_b) - (1-2\alpha)\Delta_{bc} \tag{2}$$

To prove the compliance with risk α the party has to undershoot its obligation with the value $(1-2\alpha)\Delta_{bc}$, dependent on the uncertainty measure Δ_{bc}.

The condition (2) can be also rewritten as

$$\hat{r} = \hat{x}(t_c)/\hat{x}(t_b) \leq 1 - \delta - (1-2\alpha)R_{bc} \tag{3}$$

where $\hat{r}$ is the estimated reduction factor and $R_{bc} = \Delta_{bc}/\hat{x}(t_b)$ is the half relative uncertainty interval with respect to the estimated emission in the basic year $\hat{x}(t_b)$. To relate the uncertainty to the emission estimate in the commitment year $\hat{x}(t_c)$ it must be multiplied by the estimated reduction factor $\hat{r}$. Analogously other relative values introduced in the sequel can be transformed.

It is seen from (3) that the compliance with risk α reduces to redefinition of the reduction factor

$$\delta \qquad \rightarrow \qquad \delta_U = \delta + (1-2\alpha)R_{bc} \tag{4}$$

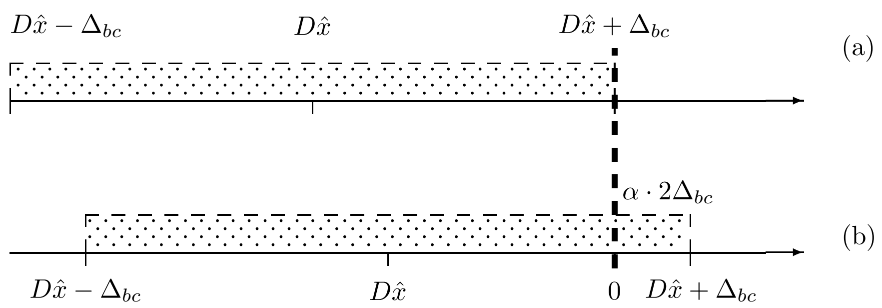

Figure 1: Full compliance (a) and the compliance with risk α (b) in the interval uncertainty approach.

Stochastic type uncertainty. Let us assume now that $\hat{x}(t)$ is normally distributed with the mean $E[\hat{x}(t)] = x(t)$ and variance $var[\hat{x}(t)] = \sigma^2$, with obvious notations σ_b^2 and σ_c^2 in the years $t = t_b$ and $t = t_c$, respectively. Wider class of distributions can be considered but it is out of scope of this paper. The variable $\hat{x}(t_c) - (1-\delta)\hat{x}(t_b)$ is then normal with the mean $x(t_c) - (1-\delta)x(t_b)$ and the variance

$$\sigma_{bc}^2 = (1-\delta)^2\sigma_b^2 + 2(1-\delta)\rho_{bc}\sigma_b\sigma_c + \sigma_c^2$$

where ρ_{bc} is the correlation coefficient of $\hat{x}(t_b)$ and $\hat{x}(t_c)$.

We require that the probability of noncompliance is not higher than α

$$\mathcal{P}\{\frac{(1-\delta)\hat{x}(t_b) - \hat{x}(t_c) - (1-\delta)x(t_b) + x(t_c)}{\sigma_{bc}} \geq q_{1-\alpha}\} \leq \alpha$$

where $q_{1-\alpha}$ is the $(1-\alpha)$th quantile of the standard normal distribution. This provides the condition

$$\hat{x}(t_c) \leq (1-\delta)\hat{x}(t_b) - (1-\delta)x(t_b) + x(t_c) - q_{1-\alpha}\sigma_{bc} \tag{5}$$

If $x(t_c) > (1-\delta)x(t_b)$, then (5) holds when the following is true

$$\hat{x}(t_c) \leq (1-\delta)\hat{x}(t_b) - q_{1-\alpha)}\sigma_{bc} \tag{6}$$

If $x(t_c) < (1-\delta)x(t_b)$, then the committed obligation is fulfilled anyway. Thus, we conclude that fulfillment of (6) is sufficient for proving compliance with risk α in the stochastic approach. A sketch on Fig. 2 shows analogy of the stochastic and the interval approaches.

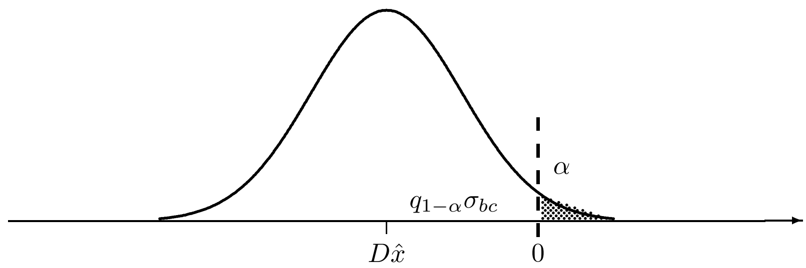

Figure 2: Compliance with risk α in the stochastic approach.

Condition (6) can be also formulated as

$$\hat{r} = \hat{x}(t_c)/\hat{x}(t_b) \leq 1 - \delta - q_{1-\alpha}R_{bc}$$

where $R_{bc} = \sigma_{bc}/\hat{x}(t_b)$. This case is reduced to redefinition of the reduction factor to $\delta_U = \delta + q_{1-\alpha}R_{bc}$.

4 Adjustment of the basic committed level

A critique of the undershooting concept may be connected with increase of the reduction caused by additional expression dependent on uncertainty. This way more than the agreed 5.2% estimated reduction would occur. This excess reduction can be simply corrected by appropriately shifting the reference reduction level. The idea presented here is to compare the uncertainty distributions with a reference one, which satisfies the original committed obligation and has a chosen uncertainty measure. More specifically, we require that both the reference distribution and the distribution of a party considered have the same upper $(1-\alpha)$th limits of their uncertainty intervals, see Figs. 3 and 4.

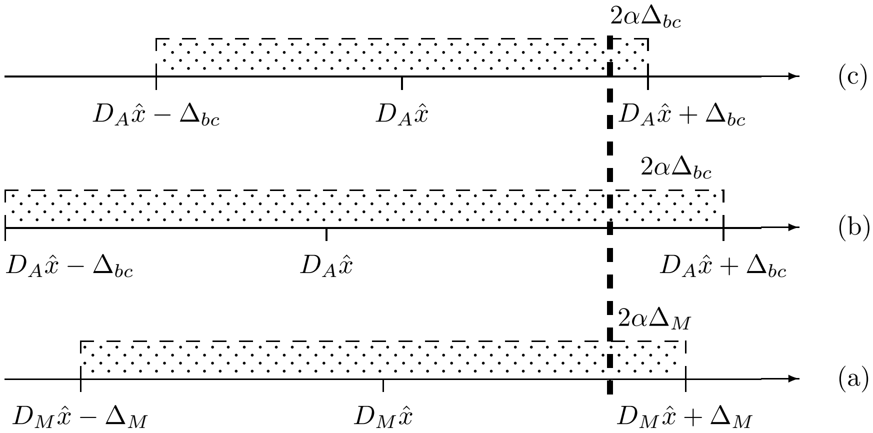

Figure 3: Adjustment of the committed level in the interval uncertainty approach, (a) reference model, (b) $\Delta_{bc} > \Delta_M$, (c) $\Delta_{bc} < \Delta_M$.

Interval type uncertainty. The reference model distribution has to satisfy exactly the committed reduction level and therefore its reduction factor is δ. At its upper limit of the $(1-\alpha)$th uncertainty interval it holds $\hat{x}(t_c) = (1-\delta)\hat{x}(t_b) + (1-2\alpha)\Delta_M$, where Δ_M is the chosen parameter – the uncertainty measure. Similarly, for the same upper limit of the party with the adjusted committed factor δ_A we have $\hat{x}(t_c) = (1-\delta_A)\hat{x}(t_b) + (1-2\alpha)\Delta_{bc}$. As both these upper limits have to be equal we get the equation, see also Fig. 3

$$(1-\delta_A)\hat{x}(t_b) + (1-2\alpha)\Delta_{bc} = (1-\delta)\hat{x}(t_b) + (1-2\alpha)\Delta_M$$

This yields the following relationship for the redefinition of the reduction factor

$$\delta \qquad \rightarrow \qquad \delta_A = \delta - (1-2\alpha)(R_M - R_{bc}) \tag{7}$$

where $R_M = \Delta_M/\hat{x}(t_b)$. The reduction factor δ_A is smaller than δ_U and the difference is

$$\delta_U - \delta_A = (1-2\alpha)R_M$$

It can be also reformulated as

$$\delta_A = \delta_U - (1-2\alpha)R_M = \delta_{AU} + (1-2\alpha)R_{bc}$$

This expression is analogous to (3). Then, we can also interpret

$$\delta_{AU} = \delta - (1-2\alpha)R_M$$

as the shifted δ in the condition (2).

Stochastic type uncertainty. Likewise, for the stochastic approach we get, see Fig. 4

$$(1-\delta_A)\hat{x}(t_b) + q_{1-\alpha}\sigma_{bc} = (1-\delta)\hat{x}(t_b) + q_{1-\alpha}\sigma_M$$

where σ_M is the chosen parameter – the standard deviation of the reference distribution. Finally

$$\delta \quad \rightarrow \quad \delta_A = \delta - q_{1-\alpha}(R_M - R_{bc}) \tag{8}$$

where $R_M = \sigma_M/\hat{x}(t_b)$. And analogously to the interval uncertainty case we get $\delta_{AU} = \delta - q_{1-\alpha}R_M$ as the shifted δ in condition (6).

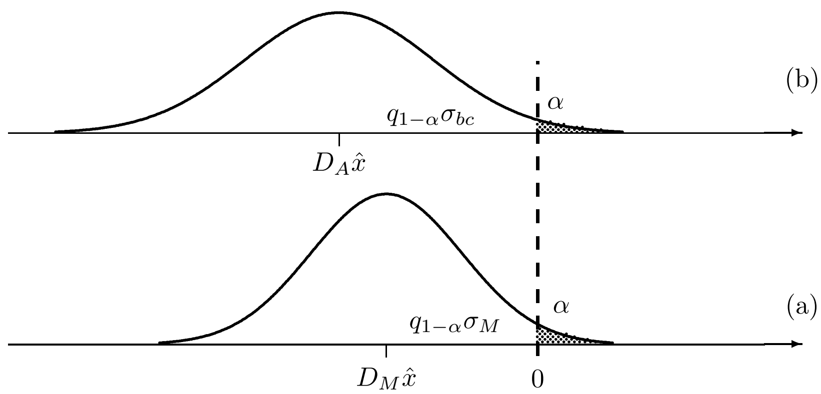

Figure 4: Adjustment of the committed level in the stochastic approach: (a) reference model, (b) $\sigma_{bc} > \sigma_M$.

Choice of R_M. An obvious choice of R_M is to keep possibly unchanged the overall reduction level. Several interpretations are, however, possible, even if only the interval uncertainty is considered, as it is in the sequel. Let us assume that N parties, $i = 1, \ldots, N$, take part in the Kyoto reduction project. We can require that mean committed reduction fractions before and after adjustment are equal, i. e. $\frac{1}{N}\Sigma_{i=1}^N \delta_A^{(i)} = \frac{1}{N}\Sigma_{i=1}^N \delta^{(i)}$. After inserting for $\delta_A^{(i)}$ from (7) this may induce two conditions:

(i) with constant R_M

$$R_M = \frac{1}{N}\Sigma_{i=1}^N R_{bc}^{(i)}$$

(ii) with constant Δ_M (similar for σ_M)

$$\Delta_M = \frac{\Sigma_{i=1}^N R_{bc}^{(i)}}{\Sigma_{i=1}^N 1/\hat{x}^{(i)}(t_b)}$$

Alternatively, we can require that mean committed reduction quota is constant, i. e. $\frac{1}{N}\Sigma_{i=1}^N \delta_A^{(i)}\hat{x}^{(i)}(t_b) = \frac{1}{N}\Sigma_{i=1}^N \delta^{(i)}\hat{x}^{(i)}(t_b)$. The two resulting conditions are as follows:

(iii) with constant R_M

$$R_M = \frac{\Sigma_{i=1}^N \Delta_{bc}^{(i)}}{\Sigma_{i=1}^N \hat{x}^{(i)}(t_b)}$$

(iv) with constant Δ_M (similar for σ_M)

$$\Delta_M = \frac{1}{N}\Sigma_{i=1}^N \Delta_{bc}^{(i)}$$

5 Uncertainties in emission trading

Admitting the above compliance proving policy it is possible to consider uncertainty in emission trading and this way to provide for different quality of this good. The main idea of this proposition consists in transferring the uncertainty to the buyer together with the traded quota of emission and including it in the buyer's emission balance. Only interval type uncertainty will be considered in this and the next section. Stochastic uncertainty introduces nonlinearities and requires longer derivations, see [8]. Moreover, neat extension for the tradable permits is not obvious for the stochastic case.

Let us consider a selling party, recognized by the superscript S in variables, with its uncertainty of emission inventory in the commitment year characterized by Δ_c^S or $R_c^S = \Delta_c^S/\hat{x}^S(t_c)$. Its unit $\hat{E}^S$ of the sold estimated emission brings with it the uncertainty

$$\hat{E}^S R_c^S = \frac{\hat{E}^S}{\hat{x}^S(t_c)}\Delta_c^S = \hat{e}^S \Delta_c^S$$

where $\hat{e}^S = \hat{E}^S/\hat{x}(t_c)$.

If the buying party, recognized by the superscript B, purchases n units $\hat{E}^S$, then its emission balance becomes

$$\hat{x}^B(t_c) - n\hat{E}^S$$

Its uncertainty, after inclusion of freshly bought one, is

$$\Delta_{bc}^B + n\hat{e}^S\Delta_c^S$$

Before the trade the following compliance-proving-with-risk-α inequality had to be satisfied

$$\hat{x}^B(t_c) + (1-2\alpha)[\Delta_c^B + (1-\delta^B)\Delta_b^B] \le (1-\delta^B)\hat{x}^B(t_b) \tag{9}$$

After the trade it changes to

$$\hat{x}^B(t_c) - n\hat{E}^S + (1-2\alpha)[\Delta_c^B + n\hat{e}^S\Delta_c^S + (1-\delta^B)\Delta_b^B \le (1-\delta^B)\hat{x}^B(t_b) \tag{10}$$

Comparing (9) and (10) it is seen that they differ in the following component, which will be called *the effective traded emission*

$$nE_{eff} = n\hat{E}^S - n(1-2\alpha)\hat{e}^S\Delta_c^S = n\hat{E}^S[1-(1-2\alpha)R_c^S]$$

The effective reduction in the buyer balance from one purchased unit $\hat{E}^S$ is

$$E_{eff} = \hat{E}^S[1-(1-2\alpha)R_c^S] \tag{11}$$

Thus, the bigger the seller's uncertainty is the less the purchased unit counts for the buyer.

Note that the efficient emission is directly subtracted from the buyer emission inventory, neglecting any uncertainty considerations.

6 Tradable permits under uncertainty

Usual instruments applied for limitation of a pollutant emission are tradable emission permits. The theory of the tradable permits has been elaborated for exactly known emissions [6]. With big uncertainties, like in the GHG case, the efficient emission units introduced in the previous section may be used as the units of tradable permits. That is, one unit U of *the effective tradable permit* is calculated as

$$U = \hat{E}[1 - (1 - 2\alpha)R] \tag{12}$$

where $\hat{E}$ is the unit of estimated emission. Other way round, the emission $\hat{x}(t)$ is equivalent to $\hat{x}(t)[1 - (1 - 2\alpha)R]$ units of the effective tradable permits.

According to condition (2), in the commitment year a party has permission to emit $\hat{x}(t_c)$ units of GHG satisfying

$$\hat{x}(t_c) \leq (1 - \delta)\hat{x}(t_b) - (1 - 2\alpha)\Delta_{bc} = (1 - \delta)[1 - (1 - 2\alpha)R_b]\hat{x}(t_b) - (1 - 2\alpha)\Delta_c$$

Adding to both sides $(1 - 2\alpha)\Delta_c$ and denoting, according to (12), $l(t) = [1 - (1 - 2\alpha)R]\hat{x}(t)$ – the number of the effective permits equivalent to the emission $\hat{x}(t)$, with $t = t_c, R = R_c = \Delta_c/\hat{x}(t_c)$ or $t = t_b, R = R_b = \Delta_b/\hat{x}(t_b)$, yields

$$\frac{1 + (1 - 2\alpha)R_c}{1 - (1 - 2\alpha)R_c} l(t_c) \leq (1 - \delta)l(t_b)$$

As for the usual R_c it holds $(1 - 2\alpha)R_c \ll 1$, then

$$l(t_c) \leq (1 - \delta)\frac{1 - (1 - 2\alpha)R_c}{1 + (1 - 2\alpha)R_c} l(t_b) \approx [1 - \delta - 2(1 - 2\alpha)R_c]l(t_b) \tag{13}$$

So, (13) expresses commitment condition in the effective tradable permits. After approximation, it has the same form as the original commitment condition in estimated emission. But the reduced fraction of the effective tradable permits is increased with an additional component associated with uncertainty and is now

$$\delta \qquad \rightarrow \qquad \delta_p = \delta + 2(1 - 2\alpha)R_c$$

To include adjustment of the basic committed level of Sec. 4, the reduction factor δ in (2) has to be changed to $\delta_{AU} = \delta - (1 - 2\alpha)R_M$. Then, arguing as above, after some algebraic manipulation (2) can be transformed to

$$l(t_c) \leq \frac{1 - (1 - 2\alpha)R_c}{1 + (1 - 2\alpha)R_c}[(1 - \delta)l(t_b) + (1 - 2\alpha)R_M\hat{x}(t_b)] \approx$$

$$\approx [1 - \delta - 2(1 - 2\alpha)R_c]l(t_b) + \frac{(1 - 2\alpha)R_M}{1 + (1 - 2\alpha)R_c}[1 - (1 - 2\alpha)R_c]\hat{x}(t_b)$$

As $(1 - 2\alpha)R_M/[1 + (1 - 2\alpha)R_c] \approx (1 - 2\alpha)R_M$, then approximately we get

$$l(t_c) \leq [1 - \delta - (1 - 2\alpha)(2R_c - R_M)]l(t_b) + (1 - 2\alpha)^2 R_M(R_b - R_c)\hat{x}(t_b)$$

Finally, noticing that

$$\frac{(1-2\alpha)^2 R_M(R_b - R_c)\hat{x}(t_b)}{[1-\delta-(1-2\alpha)(2R_c - R_M)][1-(1-2\alpha)R_b]\hat{x}(t_b)} \ll 1$$

we have an approximate condition

$$l(t_c) \leq [1-\delta-(1-2\alpha)(2R_c - R_M)]l(t_b)$$

This provides the reduction fraction for permits (with adjustment)

$$\delta \qquad \rightarrow \qquad \delta_{pA} = \delta + (1-2\alpha)(2R_c - R_M)$$

Thus, the compliance proving and trading mechanism with the uncertain observations and adjustment of the basic committed level requires the following steps. At a (successive) basic year the allotted estimated emissions are converted to the effective permits according to the expression

$$l(t_b) = \hat{x}(t_b)[1-(1-2\alpha)R_b] \tag{14}$$

The committed obligations, in effective permits, in the commitment year are calculated from the condition

$$l(t_c) \leq (1-\delta_{pA})l(t_b) = [1-\delta-(1-2\alpha)(2R_c - R_M)]l(t_b) \tag{15}$$

which is equivalent to the estimated emission

$$\hat{x}(t_c) = \frac{l(t_c)}{1-(1-2\alpha)R_c} \approx l(t_c)[1+(1-2\alpha)R_c] \tag{16}$$

The effective permits $l(t_c)$ can be traded and directly added to the effective permits of any party taking part in the project.

Let us notice that if $R_{bc} = 2R_c$ and $R_M = R_{bc}$, i.e. uncertainty of the party equals the reference one, then $R_M = 2R_c$ and therefore $\delta_{pA} = \delta$. In this case (15) reduces to the condition $l(t_c) \leq (1-\delta)l(t_b)$ where the reduction fraction is equal to the original one.

The above scheme reduces the trade in the uncertain case to the classical tradable permits problem. The effective permits are traded and counted without explicit consideration of the uncertainties in the emission inventories.

7 Conclusions

The above reasoning can be readily extended to the case when uncertainty of different emission actions can be considered in trading. Then, the separate uncertainty measures R_c connected with different activities could be used for determining the number of the effective tradable permits.

The idea can also be applied to other flexible mechanisms, provided the respective uncertainty measures are known for them.

The presented approach of including uncertainty in the value of emissions can solve the problem of different qualities of emission inventories in emission compliance proving and emission trading. Its application requires additional negotiations and agreements between parties participating in the emission reduction project. The most difficult points in negotiations might be changes of committed reductions, although they may be not so big when the adjustment of the committed reduction levels is done. Some free parameters may help to find the most convenient solution.

The advantage of the presented approach is in complete treatment of the uncertainty problem and its reduction to known case of exact observations. To apply it the knowledge of uncertainty estimates of inventories or particular activities for all parties involved is required.

Acknowledgment Partial financial support from the Polish State Scientific Research Committee within the grant 3PO4G12024 is gratefully acknowledged.

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