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Abstract

A solution for compliance and emission trading between companies in case of big uncertainties in emission observations is proposed. It consists in adjusting the emission estimate with a value dependent on a risk of noncompliance. This idea is further transfered to definition of effective permits, whose magnitudes depend on the risk. They can be traded on an ordinary basis, similarly to the usual permits. The market with effective permits is outlined. Estimated adjustments of emissions and effective permits for different emission sources are calculated for data from the literature.

CE Database subject headings: emission inventories, emission limit, uncertainty, trade

1 Introduction

Uncertainty of greenhouse gas (GHG) emissions estimates varies considerably between different emission activities. Having this in mind one can think of better or poorer quality emission estimates or more or less credible reduction of the GHG emissions. When dealing with the emission trading, 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. Thus, the uncertainty seems to become a big problem both in the compliance proving and in emission permits trading.

This problem has not been discussed too much in the literature in this context. More has been done in the context of emissions trade between Kyoto parties, see e.g.(Lieberman et al. 2007). Some considerations on excluding most uncertain activities from the emission trading were mentioned e.g. in (Monni et al. 2007) and (Winiwarter 2007). In (Godal et al. 2003) undershooting as the basis for proving compliance was considered. Similar ideas were formulated in (Gillenwater et al. 2007) and (Gupta et al. 2003). Also argumentation in this paper uses ideas related to the undershooting concept as far as the compliance proving is concerned. However, it will be interpreted here as adjustment of the emission estimates, following the way proposed in (Gillenwater et al. 2007).

Our proposition starts with increasing the emission estimates to maintain some predefined risk that the real (unknown) emission may happen not to satisfy the reduction obligation. Section 2 formulates the rule of adjustment of estimated emissions. It means that apart of observed (calculated in the inventory) greenhouse gas emission also some unobserved emission, proportional to the inventory uncertainty measure, is added to the emission estimate before checking compliance with the imposed limits. For illustration we present adjustments of emission limits for some IPCC emission categories having different inventory uncertainty.

Then, the compliance proving rule proposed in the paper is a starting point for reevaluation of the traded units of emissions. This is done by assuming that the uncertainty of the purchased 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 value for the buyer.

In sections 3 and 4 this idea is transfered to definition of an emission permit under observation uncertainty. The proposed effective emission permit includes uncertainty in the following way: a party with big inventory uncertainty is allocated less emission permits than a party with the same emission and smaller uncertainty. The effective permits are subject to ordinary trading, as in the case of permits with exact knowledge of emissions.

In the paper we assume the deterministic interval uncertainty. Solutions for checking the compliance were also discussed for the stochastic distribution of errors, see (Nahorski et al. 2007). However, nonlinearities inherent in the algebra for the stochastic case did not allow us to fully design the market rules for the emission permits. That is why argumentation in this paper is restricted to the interval type of uncertainty only. Free parameters, and specifically the risk taken, can help in solving this question. Choice of risk parameter in our interval framework as related to the stochastic consideration is discussed in section 5. Section 6 concludes the paper.

2 Compliance

By x we denote the real, unknown emission of a party. Because of imposed limit, the following inequality should be satisfied by a company

$$x \leq L \tag{1}$$

where L is the limit, for example expressed in allocated emission permits. Generally, emissions are not known exactly and can be only estimated. These estimates are uncertain, as they are subject to estimation error. Throughout the paper it will be assumed that the uncertainty is of the interval type. Best available estimate of emission is denoted as

$$\hat{x} \tag{2}$$

Moreover, emissions arising from different sources can be calculated with different uncertainties. In Table 1, cited from (Monni et al. 2007), examples of emission uncertainty values for some IPPC categories are shown.

[Table 1 approximately here.]

Thus, the following question arises: how can we decide that the company has satisfied the imposed limit. If the error of estimated emission in (2) is symmetric, then equality $\hat{x} = L$ gives equal chances for (1) to be true or to be false. Our solution proposed in this section lies in increasing chances of (1) to be true.

Assuming that the uncertainty intervals are $\pm\Delta$ we have

$$x \in [\hat{x} - \Delta, \hat{x} + \Delta]$$

To be fully credible, that is to be sure that (1) is satisfied even in the worst case, the party should prove $\hat{x} + \Delta \leq L$, see Fig.1(a). Our proposition is to admit for some agreed chance of not satisfying the obligations. In other wording, we want to take risk not greater then α $(0 \leq \alpha \leq 0.5)$ that the reduction is not fullfilled. We then say that the party *proves the compliance with risk* α if $\hat{x} + \Delta \leq L + 2\alpha\Delta$, see Fig.1(b) for the geometrical interpretation. The lower bound $\alpha = 0$ corresponds to full credibility. The value $\alpha = 0.5$ corresponds to ignoring completely tbe uncertainty. The parameter α is to be set beforehand, common for all market participants. After simple algebraic manipulations the above definition leads to the condition

$$\hat{x} + (1 - 2\alpha)\Delta \leq L \tag{3}$$

Thus, to prove the compliance with risk α the party has to adjust its emission estimate with the value $(1 - 2\alpha)\Delta$, dependent on the uncertainty measure Δ.

[Figure 1 approximately here.]

Denoting by R the half relative uncertainty interval with respect to the estimated emission in the basic year $\hat{x}$

$$R = \frac{\Delta}{\hat{x}}$$

the condition (3) can be also rewritten as

$$1 + (1 - 2\alpha)R \leq \frac{L}{\hat{x}} \tag{4}$$

Table 2 lists increase in emissions, in percents, for different IPCC categories for few values of α, according to the above rules.

[Table 2 approximately here.]

Subtracting $(1-2\alpha)\Delta$ from both sides of (3) it is seen that the compliance with risk α may be also reduced to redefinition of the limit

$$L \quad \longrightarrow \quad L_U = L - (1-2\alpha)\Delta \tag{5}$$

This interpretation is connected with the earlier mentioned undershooting approach. Although both approaches are mathematically equivalent, yet shifting of limit value is politically more difficult to accept, as also argumented in (Gillenwater et al. 2007).

3 Tradable permits under uncertainty

Admitting the above compliance checking rule it is possible to include uncertainty in emission trading and this way 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.

Let us consider a selling party, recognized by the superscript S in variables. The uncertainty used in proving compliance of the selling party is Δ^S or $R^S = \Delta^S/\hat{x}^S$. Thus, the unit $\hat{E}^S$ of the sold estimated emission brings with it the uncertainty proportional to the relative uncertainty R^S

$$\hat{E}^S R^S = \frac{\hat{E}^S}{\hat{x}^S}\Delta^S = \hat{e}^S\Delta^S$$

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

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

$$\hat{x}^B - n\hat{E}^S \tag{6}$$

We calculate the uncertainty of the buying country, after inclusion of freshly bought units, as

$$\Delta^B + n\hat{e}^S\Delta^S \tag{7}$$

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

$$\hat{x}^B + (1-2\alpha)\Delta^B \leq L^B \tag{8}$$

After the trade it changes to

$$\hat{x}^B - n\hat{E}^S + (1-2\alpha)[\Delta^B + n\hat{e}^S\Delta^S] \leq L^B \tag{9}$$

Comparing (8) and (9) it is seen that they differ in the following component, which will be called *the effective traded emission*

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

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

$$E_{eff} = [1-(1-2\alpha)R^S]\hat{E}^S \tag{10}$$

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 estimate, without any uncertainty considerations.

4 Emission trading

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 (Montgomery 1972). With big uncertainties, like in the GHG case, the efficient emission units introduced in the previous section may be used as the units of effective tradable permits.

One unit E_{eff} of *the effective tradable permit* is then defined as

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

where $\hat{E}$ is the unit of estimated emission and R is the relative uncertainty of $\hat{x}$. Other way round, the emission $\hat{x}$ is equivalent to $\hat{x}[1-(1-2\alpha)R]$ units of the effective tradable permits. The formula directly reflects the following rule: higher the uncertainty – less units of effective emission permits a party is allocated with.

[Table 3 approximately here.]

Let us consider a company taking part in the emission trade. According to condition (3), the company has permission to emit $\hat{x}$ units of GHG satisfying

$$\hat{x} + (1-2\alpha)\Delta \leq L \tag{12}$$

Denoting, according to (11), the numbers of the effective permits equivalent to the emission

$$l = [1-(1-2\alpha)R]\hat{x} \tag{13}$$

the condition (12) yields

$$\frac{1+(1-2\alpha)R}{1-(1-2\alpha)R} l \leq L$$

or

$$l \leq \frac{1-(1-2\alpha)R}{1+(1-2\alpha)R} L \tag{14}$$

So, (14) expresses commitment condition in the effective tradable permits. It has the same form as the original commitment condition in estimated emission (3) with redefinition of the limit

$$L \qquad \rightarrow \qquad L_p = \frac{1-(1-2\alpha)R}{1+(1-2\alpha)R} L \tag{15}$$

Thus, the compliance and emission trading market with the uncertain observations and adjustment of the basic committed level requires the following steps. The allocated limit is converted according to the expression (15). The obligations in effective permits are expressed by the condition

$$l \leq L_p \tag{16}$$

They are equivalent to the following estimated emission

$$\hat{x} = \frac{l}{1 - (1 - 2\alpha)R} \tag{17}$$

The effective permits l can be traded and directly added to the effective permits of any party taking part in the project, independently from their emission uncertainties. Thus, they take the role of the usual emission permits on the market.

The above scheme reduces the trade in the uncertain case to the classical tradable permits problem. The transformations scale down the emission limit but at the same time scale down the emission units, see Table 3. The effective permits are traded and counted without explicit consideration of the uncertainties in the emission inventories.

5 Discussion

The results presented in Tables 2 and 3 show that the uncertainty makes considerable corrections – additions to the adjusted emissions and subtractions from the efficient emissions. The corrections depend on the uncertainty level and on the risk α. For small uncertainties, of few percents, corrections are not big. For example, for $\alpha = 0.3$ corrections take values between one third and half of the uncertainty range. For bigger uncertainties the corrections reach the values up to 40%.

It may be argued that bigger risk α should be considered in the rules proposed. The interval uncertainty approach is actually a simplification, as it is commonly assumed that the emission estimates have a stochastic distribution, mostly a Gaussian one (Rypdal and Winiwarter 2001). In the stochastic approach some problems in the derivations of the efficient emissions arise due to nonlinearities, see (Nahorski et al. 2007). But compliance rules can be derived even for the stochastic case and provide the condition

$$\hat{x} + q_{1-\alpha}\sigma \leq L \tag{18}$$

where σ is the standard deviation of the distribution. In order to have equal corrections in the interval approach rule (3) and the stochastic approach rule (18), the following condition has to be satisfied

$$(1 - 2\alpha_I)\Delta = q_{1-\alpha_S}\sigma \tag{19}$$

where the subscripts I and S indicate the interval and the stochastic case, respectively.

We assume that $\Delta = k\sigma$. For the Gaussian distributions usually $k = 2$ is adopted. Thus in our one-side case in the interval approach around 2.5% of the probability mass is left apart. For $k = 3$ only around 0.1% of the probability mass is neglected. With $\Delta = k\sigma$ the condition (19) can be transformed to

$$\alpha_I = \frac{1}{2}(1 - \frac{1}{k}q_{1-\alpha_S}) \tag{20}$$

Figure 2 illustrates relationship between adopted risk in interval case α_I and stochastic case α_S as stated in equation (20) for $k = 2$ (dashed line) and $k = 3$ (solid line).

[Figure 2 approximately here.]

In Table 4 values α_I corresponding to few values of α_S for $k = 2$ and $k = 3$ are depicted. It can be noticed that α_I's take bigger values than α_S's. Practically α_I of 20% or even better 30% seem to be appropriate to be used in the compliance rule.

[Table 4 approximately here.]

With these values of α_I the corrections in adjusted and efficient emissions for the sources included in EU emission trading scheme take values of 1 to 4%, which can be neglected in practical application. Inclusion of new sources, with much higher uncertainties of emissions, changes the situation. For them, corrections are much bigger, up to 40%, and can not be neglected. This is when the rules proposed earlier find their main justification.

6 Conclusions

The proposed approach of including uncertainty in the reported emissions can be used to solve the problem of different qualities of emissions encountered in compliance and emission trading, due to high and nonhomogeneous estimation errors corresponding to different greenhouse gases emissions sources. The advantage of the presented approach is in complete treatment of the uncertainty problem and its reduction to the known case for exact knowledge of emissions. In particular, it gives bigger chances of real satisfaction of the imposed limits and therefore provides greater credibility of the compliance rules. It also reduces the permit trade under inventory uncertainty to the known permit trade with no uncertainty. To apply the approach, the knowledge of uncertainty estimates of inventories or particular activities for all parties involved is needed. Estimation and documentation of emission uncertainty estimates is quite a popular subject of many research projects in the field of inventory analysis.

While adequate conditions for compliance and emission trade with interval type uncertainties has been presented, the definition of effective permits in a stochastic case still remains unsolved due to encountered nonlinearities. Yet, the stochastic case seems to reflect better the reality. The abatement costs for the same risk α is lower in a stochastic case with normal probability distributions than in an interval case. This is due to the effect of concentration of probability around the mean value. This problem can be easily solved for the compliance using bigger values of the risk coefficient α, as shown in Table 4. These bigger values of α provide at the same time smaller corrections, as compared to the case with neglected uncertainties. As in choosing α a tradeoff between risk of noncompliance and costs of additional reduction of greenhouse gas emission has to be made, this correspondence of α's for the interval and stochastic approaches is a good information from the cost-saving point of view.

Nevertheless, corrections for more uncertain emission sources take quite big values, even for $\alpha = 0.3$. This indicates to a necessity of applying more sofisticated rules in compliance and permission trading for emission sources with very spanned uncertainties.

7 Notation

The following symbols are used in the paper:

^{B} (superscript) - buying party;
$\hat{E}$ - unit of estimated emission;
E_{eff} - unit of effective tradable permit;
L - emission limit;
L_p - emission limit expressed in effective permits;
L_U - emission limit redefined with undershooting rule;
R - half relative uncertainty interval;
^{S} (superscipt) - selling party;
$\hat{e}^S$ - unit of sold emission in relation to overall seller emission;
k - parameter relating uncertainty interval with standard deviation;
l - effective permits;
n - number of exchanged units of emission;
q - quantile;
x - real unknown emission;
$\hat{x}$ - best available estimate of emission;
$\pm\Delta$ - uncertainty intervals;
α - risk of noncompliance;
α_I - risk of noncompliance for interval case;
α_S - risk of noncompliance for stochastic case;
σ - standard deviation.

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[Table 1]

Table 1: Estimates of emission uncertainties for some IPCC categories, in %.

IPCC category	Emission source	Gas	Uncertainty
Sources included in EU emission trading scheme (old member states)			
1A	Stationary combustion	CO_2	±3%
2A	Cement and lime	CO_2	±7%
2C	Metal industry	CO_2	±6%
Sources included in EU emission trading scheme (new member states)			
1A	Stationary combustion	CO_2	±7%
2A	Cement and lime	CO_2	±10%
2C	Metal industry	CO_2	±8%
Sources included in extended EU emission trading scheme (old member states)			
1A	Stationary combustion	CH_4	±50%
1A	Stationary combustion	N_2O	-100 to +550%
Sources included in addition in Kyoto emission trading scheme (old member states)			
1A	Stationary combustion not included above	CO_2	±7%
1A	Stationary combustion not included above	CH_4	±50%
1A	Stationary combustion not included above	N_2O	-100 to +550%
1A3	Transportation	CO_2	±5%
1A3	Transportation	CH_4	±50%
1A3	Transportation	N_2O	-100 to + 550%
1B	Fugitive emissions from fuels	CO_2, CH_4	±30%
2B	Chemical products	CO_2	±20%
2B	Chemical products	N_2O	±15%
2	HFC emissions	HFCs	±40%
2	PFC emissions	PFCs	±40%
2	SF_6 emissions	SF_6	±30%
3	Solvent and other product use	CO_2, N_2O	±30%
4A	Enteric fermantation	CH_4	±40%
4B	Manure management	CH_4	±40%
4B	Manure management	N_2O	-70 to +150%
4C	Rice cultivation	CH_4	-80 to +200%
4D	Agricultural soils	N_2O	-100 to +1000%
6A	Solid waste disposal on land	CH_4	±45%
6B	Wastewater management	CH_4	±50%
6B	Wastewater management	N_2O	-70 to +150%
6C	Waste incineration	CO_2	±20%
5	LULUCF*	CO_2	±90%

* – Stands for Land Use Change and Forestry.
Cited from (Monni et al. 2007).

[Table 2]

Table 2: Adjustments of emissions for some emission categories, in %.

IPCC category	Gas	Uncertainty	$(1-2\alpha)R$		
			$\alpha = 0.1$	$\alpha = 0.2$	$\alpha = 0.3$
Sources included in EU emission trading scheme (OMS[1])					
1A	CO_2	±3%	2.4	1.8	1.2
2A	CO_2	±7%	5.6	4.2	2.8
2C	CO_2	±6%	4.8	3.6	2.4
Sources included in EU emission trading scheme (NMS[1])					
1A	CO_2	±7%	5.6	4.2	2.8
2A	CO_2	±10%	8.0	6.0	4.0
2C	CO_2	±8%	6.4	4.8	3.2
Sources included in extended EU emission trading scheme (OMS[1])					
1A	CH_4	±50%	40	30	20
1A	N_2O	-100 to +550%[2]	80	60	40
Sources included in addition in Kyoto emission trading scheme (OMS[1])					
1A	CO_2	±7%	5.6	4.2	2.8
1A	CH_4	±50%	40	30	20
1A	N_2O	-100 to +550%[2]	80	60	40
1A3	CO_2	±5%	4.0	3.0	2.0
1A3	CH_4	±50%	40	30	20
1A3	N_2O	-100 to + 550%[2]	80	60	40
1B	CO_2, CH_4	±30%	24	18	12
2B	CO_2	±20%	16	12	8
2B	N_2O	±15%	12	9	6
2	HFCs	±40%	32	24	16
2	PFCs	±40%	32	24	16
2	SF_6	±30%	24	18	12
3	CO_2, N_2O	±30%	24	18	12
4A	CH_4	±40%	32	24	16
4B	CH_4	±40%	32	24	16
4B	N_2O	-70 to +150%[2]	56	42	28
4C	CH_4	-80 to +200%[2]	64	48	32
4D	N_2O	-100 to +1000%[2]	80	60	40
6A	CH_4	±45%	36	27	18
6B	CH_4	±50%	40	30	20
6B	N_2O	-70 to +150%[2]	56	42	28
6C	CO_2	±20%	16	12	8
5	CO_2	±90%	72	54	36

[1] – OMS - old member states, NMS - new member states.

[2] – Lower bound taken for further calculations.

[Table 3]

Table 3: Change of the value of emissions permits for some categories, in %.

IPCC category	Gas	Uncertainty	$E_{eff}/\hat{E}$ Risk $\alpha =$ 0.1	0.2	0.3	L_p/L Risk $\alpha =$ 0.1	0.2	0.3
Sources included in EU emission trading scheme (OMS[1])								
1A	CO_2	±3%	97.6	98.2	98.8	95.3	96.5	97.6
2A	CO_2	±7%	94.4	95.8	97.2	89.4	91.9	94.6
2C	CO_2	±6%	95.2	96.4	97.6	90.8	93.1	95.3
Sources included in EU emission trading scheme (NMS[1])								
1A	CO_2	±7%	94.4	95.8	97.2	89.4	91.9	94.6
2A	CO_2	±10%	92.0	94.0	96.0	85.2	88.7	92.3
2C	CO_2	±8%	93.6	95.2	96.8	88.0	90.8	93.8
Sources included in extended EU emission trading scheme (OMS[1])								
1A	CH_4	±50	60.0	70.0	80.0	42.9	53.8	66.7
1A	N_2O	-100 to +550%[2]	20.0	40.0	60.0	11.1	25.0	42.9
Sources included in addition in Kyoto emission trading scheme (OMS[1])								
1A	CO_2	±7%	94.4	95.8	97.2	89.4	91.9	94.6
1A	CH_4	±50%	60.0	70.0	80.0	42.9	53.8	66.7
1A	N_2O	-100 to +550%[2]	20.0	40.0	60.0	11.1	25.0	42.9
1A3	CO_2	±5%	96.0	97.0	98.0	92.3	94.2	96.1
1A3	CH_4	±50%	60.0	70.0	80.0	42.9	53.8	66.7
1A3	N_2O	-100 to + 550%[2]	20.0	40.0	60.0	11.1	25.0	42.9
1B	CO_2, CH_4	±30%	76.0	82.0	88.0	61.3	69.5	78.6
2B	CO_2	±20%	84.0	88.0	92.0	72.4	78.6	85.2
2B	N_2O	±15%	88.0	91.0	94.0	78.6	83.5	88.7
2	HFCs	±40%	68.0	76.0	84.0	51.5	61.3	72.4
2	PFCs	±40%	68.0	76.0	84.0	51.5	61.3	72.4
2	SF_6	±30%	76.0	82.0	88.0	61.3	69.5	78.6
3	CO_2, N_2O	±30%	76.0	82.0	88.0	61.3	69.5	78.6
4A	CH_4	±40%	68.0	76.0	84.0	51.5	61.3	72.4
4B	CH_4	±40%	68.0	76.0	84.0	51.5	61.3	72.4
4B	N_2O	-70 to +150%[2]	44.0	58.0	72.0	28.2	40.8	56.3
4C	CH_4	-80 to +200%[2]	36.0	52.0	68.0	22.0	35.1	51.5
4D	N_2O	-100 to +1000%[2]	20.0	40.0	60.0	11.1	25.0	42.9
6A	CH_4	±45%	64.0	73.0	82.0	47.1	57.5	69.5
6B	CH_4	±50%	60.0	70.0	80.0	42.9	53.8	66.7
6B	N_2O	-70 to +150%[2]	44.0	58.0	72.0	28.2	40.8	56.3
6C	CO_2	±20%	84.0	88.0	92.0	72.4	78.6	85.2
5	CO_2	±90%	28.0	46.0	64.0	16,3	29.9	47.1

[1] – OMS - old member states, NMS - new member states.

[2] – Lower bound taken for further calculations.

[Table 4]

Table 4: Correspondence of α_S and α_I for $k = 2$ and $k = 3$.

α_S	α_I	
	$\Delta = 2\sigma$	$\Delta = 3\sigma$
0.05	0.08	0.23
0.10	0.18	0.29
0.20	0.29	0.36
0.30	0.37	0.41

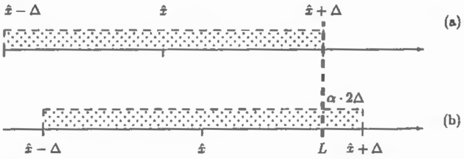

Figure 1: Full compliance (a) and the compliance with risk α (b).

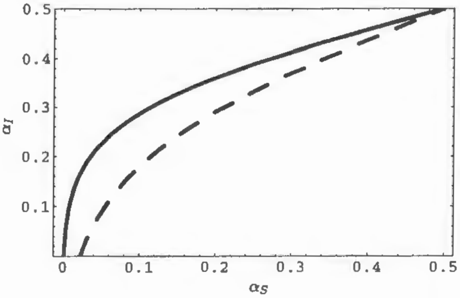

Figure 2: Relationship between α_I and α_S for $k = 2$ (dashed line) and $k = 3$ (solid line).