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I ANALIZY SYSTEMOWEJ W ZARZĄDZANIU

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# ZASTOSOWANIA INFORMATYKI I ANALIZY SYSTEMOWEJ W ZARZĄDZANIU

pod redakcją
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Książka wydana dzięki dotacji KOMITETU BADAŃ NAUKOWYCH

Książka zawiera wybór artykułów poświęconych omówieniu aktualnego stanu badań w kraju w zakresie rozwoju modeli, technik i systemów zarządzania oraz ich zastosowań w różnych dziedzinach gospodarki narodowej. Wyodrębnioną grupę stanowią artykuły omawiające aplikacyjne wyniki projektów badawczych i celowych KBN.

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Rozdział 5

# Modele, techniki i systemy zarządzania w projektach badawczych i celowych KBN

# COPING WITH UNCERTAINTY IN VERIFICATION OF THE KYOTO OBLIGATIONS[1]

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*Implementation of the Kyoto Protocol raises the question of verification of the Kyoto obligations. Estimates show that uncertainty of the emissions reported by countries is high, mainly due to the methodology of the report preparation. Thus the final verification of the obligations should take into account uncertainty of the reported emissions. This problem is considered in the paper. Our proposition for verification is based on setting a (small enough) risk of not satisfying obligations, which leads to the easy to check conditions. This can be done either within a deterministic or stochastic setup. Consequently, purchase of emissions should be associated with assimilation of the accompanying it uncertainty. Acceptance of this idea will influence emission trading rules, and in particular will change the cost of the bargained emission unit. This issue is also addressed in the paper.*

**Keywords:** Kyoyto Protocol, verification of Kyoto obligations.

## 1. Introduction

The Kyoto Protocol contains the first legally binding commitments to limit or reduce the emissions of six greenhouse gases or groups of gases ($CO_2$, $CH_4$, $N_2O$, HFCs, PFCs, and $SF_6$). For so-called Annex I Parties, the targets agreed upon under the Protocol by the first commitment period (2008 to 2012) add up to a decrease in greenhouse gas emissions of 5.2% below 1990 levels in terms of $CO_2$ equivalents ($CO_2$eq)[2]. Among other mechanisms, the Protocol endorses emissions trading (Article 17) (FCCC, 1998), see also (IPCC, 2000), (Jonas et al., 1999).

The Kyoto Protocol also mentions uncertainty. However, it does not put uncertainty (and, thus, verification) at the centre of its efforts to slow global

[1] Praca wykonana w ramach projektu badawczego KBN nr 3P04G12024.

[2] For some countries the base year is different from 1990.

warming (Nilsson et al., 2001, 2002). So far, the number of countries that have made their uncertainty assessments available is limited to Austria, Netherlands, Norway, Poland, Russia and the United Kingdom (Winiwater, Rypdal, 2001), (Jonas, Nilsson, 2001), (Amstel et al., 2000), (Rypdal, Zhang, 2000), (Gawin, 2002), (Nilsson et al., 2000), (Horabik, Nahorski, 2003) (Charles et al., 1998). Their uncertainty estimates are summarized in Table 1.

**Table 1.** First-order comparison by country: Quantified total uncertainties of net emissions that are available for 1990 and can be compared with the committed reduction in the emissions or their limited increase.

| Country | Reduction Commitment[a] [%] | Total Uncertainty [%] | GHGs Considered | LUCF[b] In- or Excluded | Reference |
|---|---|---|---|---|---|
| AT | 8<br>(10) | ~ 12<br>~ 9.8 | $CO_2$, $CH_4$, $N_2O$ | included<br>excluded | Tab. 3* |
| | | ~ 15<br>~ 7.5 | | included<br>excluded | Tab. 14* |
| NL | 8<br>(4) | ~ 4.4 | all[e] | included | Tab. 1* |
| NO | -1 | ~ 21 | all[e] | excluded | Tab. 4* |
| PL | 6 | ~ 6 | $CO_2$, $CH_4$, $N_2O$ | included | Tab. 3* |
| RU | 0 | ~ 17[c] (energy sector) | $CO_2$ | see right | p. 158* |
| UK | 8<br>(12.5) | ~ 42[d]<br>~ 19 | all[e] | included<br>excluded | Tab. 1* |

a) A positive number refers to a committed reduction in the emissions and a negative number to a limitation in their increase. A number in parentheses refers to a national GHG emission target agreed upon under the EU burden sharing.

b) Stands for Land Use Change and Forestry.

c) The uncertainties reported in (Nilsson et al., 2000) in their Russian case study (including this one) are presently scrutinized as new knowledge is unfolding, which may justify their reduction.

d) This uncertainty is derived by applying the law of uncertainty (error) propagation. (IPCC, 1998) reports a total relative uncertainty of 19% for all emissions by sources and 38% for all removals by sinks.

* Źródła: Tab. 3 (Winiwater, Rypdal, 2001), Tab. 14 (Jonas, Nilsson, 2001), Tab. 1 (Amstel et. al., 2000), Tab. 4 (Rypdal, Zhang, 2000), Tab. 3 (Gawin, 2002), p. 158 (Nilsson et al., 2000), Tab. 1 (IPCC, 1998).

e) All gases as mentioned in Annex A to the Kyoto Protocol (IPCC, 1998): $CO_2$, $CH_4$, $N_2O$, HFCs, PFCs, $SF_6$.

These findings signal difficulties associated with the verification of emission reduction commitments and, thus, with the credibility of net emissions reported on the country level. Hitting a "Kyoto target" provides little information if uncertainties are great, as it is also probable that the countries' emissions lie above or below their respective targets. The situation is even more difficult because also the targets are not exactly known due to the countries' uncertain emissions in the base year. The uncertainty estimates published up to now, see Table 1, show that this problem will cause serious difficulties for verification in all countries.

The idea developed in this paper starts with the observation that to be credible, a country with the big uncertainty should end in the commitment period with the reported emission below the target value, this being in some proportion to the measure of its uncertainty. Our proposition starts with setting this shifted down value to maintain some predefined risk that the real (unknown) emission may happen to be actually above the original target value.

The presented framework of verification has to cover rules of trading the emission savings. A purchase of an excess reduction has to take into account the inaccuracy of the seller emission. As a consequence, the emission reductions of a country with big emission uncertainty should be cheaper than those of the countries with small uncertainty. Our idea consists in an appropriate correction of the buyer's uncertainty with the uncertainty of the seller.

The idea of undershooting under inaccurate reporting has been already raised in (Godal, 2000). There, the uncertainty interval shifts down the reduction level. In this paper we introduce the concept of a risk of not satisfying the obligations. This allows us to consider the stochastic errors in reporting, in particular the normally distributed ones, and to treat both the approaches in a unified way. Although in this paper we do not consider the market optimisation model, as in (Godal, 2000), we point out to the necessity of including the uncertainty directly in the trading process. This considerably influences the trading rules.

Some consequences of applying the idea of inclusion of uncertainty in the verification process on the country level are discussed in (Horabik, Nahorski, 2003).

## 2. Verification of Committed Changes in Emissions

### 2.1. Notations and problem presentation

By $x(t)$ we denote the real (unknown) emission, as a function of time. The emission in the basic year $t_0$ will be denoted $x(t_0) = x_0$. The important years, where verifications are planned, viz. 2008–2012, will be denoted $T_i$, where for brevity $i$ = 8-12. The Kyoto Protocol is not too precise in the exact meaning of the way of verification in the commitment period 2008-2012. Taking it literally, the obligations should be satisfied in every year of this period. Argumentation in this paper goes basically along this line. However, the methodology presented can be easily used also when some aggregated value of the emissions from the commitment period, like e.g. the average value, is taken, if only the exact way of aggregation of both reported emissions and its uncertainty measures are agreed upon.

The real emission is unknown and can be only estimated. Hats will mark the estimated values, so $\hat{x}(t)$ is the estimated emission. As far, the values provided by the Annex I Parties' are considered as estimates $\hat{x}(t)$. However, these reported values might be used for the more elaborated estimation of $x(t)$. Presentation of a possible method is left for elsewhere. However, we anticipate it already in the notation used.

These estimated values are contaminated with the estimation (reporting) errors. The treatment of inaccuracies inherent in the emission estimates may be different, like e.g. interval, stochastic or fuzzy. The choice of modelling the inaccuracies is important, as this way the rules of calculus are being set.

By $\delta$ we denote the fraction of the emission to be reduced until the commitment period. Thus, in the ideal case, under perfect knowledge of the emissions, the emission at the commitment period should be not greater than $(1-\delta)x_0$. The problem arises because we can not compare directly $x(T_i)$ and $(1-\delta)x_0$ but only calculate the difference

$$\hat{x}(T_i) - \hat{x}_0(1-\delta) \tag{1}$$

where the both observed values $\hat{x}(T_i)$ and $\hat{x}_0$ are known inaccurately.

Uniform treatment of the different ways of modelling the inaccuracies requires taking into account that some of them, like stochastic ones, may involve infinite supports of their distributions. Thus, our proposition is to admit for some agreed chance of not satisfying the obligations. In other wording, we want to take risk not greater than $\alpha$ ($0 \le \alpha \le 0.5$) that the reduction in the year $T_i$ is not fulfilled. The lower bound $\alpha = 0$ corresponds to the inclusion of half or approximately half of the support (which may be practical only when it is finite) – to the middle of it or to the median, depending on an approach used. The value $\alpha = 0.5$ corresponds to ignoring completely the uncertainty. We assume that the value of $\alpha$ has been set beforehand, to be common for all parties.

## 2.2. Interval uncertainty

In this case, the difference between the unknown real emissions $x_0$ and our best estimate $\hat{x}_0$ as well as the difference between $x(T_i)$ and $\hat{x}(T_i)$ are known to be smaller than some upper bounds. Let us assume that these uncertainty intervals at $T_0$ and $T_i$ are

$$|x_0 - \hat{x}_0| \le \Delta_0, \quad |x(T_i) - \hat{x}(T_i)| \le \Delta_i \tag{2}$$

Using the interval calculus rules the combined interval uncertainty of the estimates (2) at the time point $T_i$ is

$$x(T_i) - x_0(1-\delta) \in [D\hat{x} - \Delta_{0i},\ D\hat{x} + \Delta_{0i}] \tag{3}$$

where $D\hat{x} = \hat{x}(T_i) - \hat{x}_0(1-\delta)$, $\Delta_{0i} = \Delta_i + (1-\delta)\Delta_0$. As we agree to take the risk $\alpha$ that the value $x(T_i)$ may be actually greater then $x_0(1\text{-}\delta)$, then the following condition must hold

$$\hat{x}(T_i) \le \hat{x}_0(1-\delta) - (1-2\alpha)\Delta_{0\mathrm{i}} \tag{4}$$

As $(1\text{-}\delta)\Delta_0$ will be usually close to $\Delta_i$ then from (5) we see that $\Delta_{0i} \approx 2\Delta_i$. Thus, if $\alpha$ is small, the condition (4) requires that the value $\hat{x}_0(1-\delta)$ is undershot with almost two uncertainty intervals. Taking bigger risk (bigger $\alpha$) the required undershoot may be considerably reduced.

## 2.3. Stochastic uncertainty

In the second case, the unknown real emissions $x_0$ and $x(T_i)$ can only be grasped with the help of the uncertainty distribution that underlies $\hat{x}_0$ and $\hat{x}(T_i)$. We assume that $\hat{x}_0$ and $\hat{x}(T_i)$ are normally distributed with $E(\hat{x}_0) = x_0$, $E(\hat{x}(T_i)) = x(T_i)$ and that their standard deviations are $\sigma_{\hat{x}}(0)$ and $\sigma_{\hat{x}}(T_i)$, respectively. The derivation below is actually valid for arbitrary distributions with finite variances provided $x_0(1-\delta) - x(T_i)$ is the median of the distribution of $\hat{x}_0(1-\delta) - \hat{x}(T_i)$, like in case of any symmetric distributions of $\hat{x}_0$ and $\hat{x}(T_i)$.

We require that the probability of not satisfying the obligations is $\alpha$, $0 \le \alpha \le 0.5$. This can be written as

$$P\left( \frac{\hat{x}_0(1-\delta) - \hat{x}(T_i) - x_0(1-\delta) + x(T_i)}{\sigma_{\hat{x}}} \ge q_{1-\alpha} \right) = \alpha \tag{5}$$

where $\sigma_{\hat{x}}(T_i)$ is the standard deviation of the distribution of the variable $\hat{x}_0(1-\delta) - \hat{x}(T_i)$ and $q_{1\text{-}\alpha}$ is the $(1\text{-}\alpha)$th quantile of the distribution of the corresponding standardized variable. Let us notice that due to standardization we have $q_{0.5} = 0$.

According to the rules for calculating the variance of the linear combination of two random variables it holds

$$\sigma_{\hat{x}_1}^2 = (1-\delta)^2 \sigma_{\hat{x}_1}^2(0) - 2(1-\delta)\rho_{0i}\sigma_{\hat{x}_1}(0)\sigma_{\hat{x}_1}(T_i) + \sigma_{\hat{x}_1}^2(T_i) \tag{6}$$

where $\sigma_{\hat{x}}^2(0)$ is the variance of $\hat{\mathrm{x}}_0$, $\sigma_{\hat{x}}^2(T_i)$ that of $\hat{x}(T_i)$, and $\rho_{0i}$ is the covariance of $\hat{x}_0$ and $\hat{x}(T_i)$. Equation (5) provides the condition to be satisfied with the risk $\alpha$

$$\hat{x}(T_i) \le \hat{x}_0(1-\delta) - x_0(1-\delta) + x(T_i) - q_{1-\alpha}\sigma_{\hat{x}} \tag{7}$$

As our goal is to achieve $x(T_i) = x(1\text{-}\delta)$ we assume $-x(1\text{-}\delta) + x(T_i) = 0$ which yields

$$\hat{x}(T_i) \le \hat{x}_0(1-\delta) - q_{1-\alpha}\sigma_{\hat{x}} \tag{8}$$

Calculation of $q_{1\text{-}\alpha}$ depends on common distribution of probability of the variables $\hat{x}_0$ and $\hat{x}(T_i)$, and can be in principle computed according to known rules. For the standardized normal distribution the quantiles are tabulated for different $\alpha$'s.

### 2.4. Consequences of choosing different inaccuracy models

We investigate here four uncertainty models: the interval uncertainty, and the stochastic uncertainties with the uniform, the triangular and the normal distributions.

To make the comparison possible we assume that the interval of uncertainty is $[-\Delta, \Delta]$ and that the uniform and the triangular distributions are also defined on the same interval. Then $\sigma_u = \Delta/\sqrt{3}$ and $\sigma_t = \Delta/\sqrt{6}$, where $\sigma_u$ and $\sigma_t$ are the standard deviations of the uniform and the triangular distributions, respectively. For the normal distribution we take $\sigma_n = \Delta/2$. Moreover, we assume that the uncertainties of both subtracted parts in (1) are equal, that is it holds $\Delta_i = (1-\delta)\Delta_0 = \Delta$ for the deterministic case and $\sigma_{\hat{x}}(T_i) = \sigma_{\hat{x}}(0)(1-\delta) = \sigma$ for the stochastic one. Additionally we assume that the variables $\hat{x}_0$ and $\hat{x}(T_i)$ are uncorrelated.

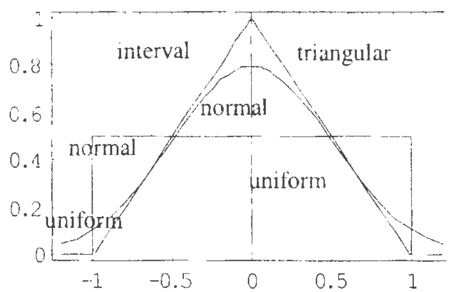


**Figure 1.** Considered probability functions.

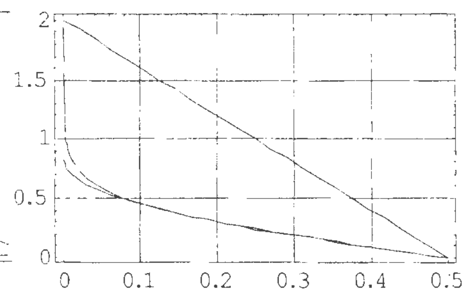


**Figure 2.** Values of $\delta_\alpha / v$ as functions of $\alpha$ for different cases.

We introduce now a common notation $\delta_\alpha = (1-2\alpha)\Delta_{0i}/\hat{x}_0$ for the deterministic and $\delta_\alpha = q_{1-\alpha}\sigma_{\hat{x}}/\hat{x}_0$ for the stochastic case. The new target to be reached is then equal to $\hat{x}_0(1-\delta-\delta_\alpha)$. Dividing $\delta_\alpha$ by $v = \Delta/\hat{x}_0$ we obtain a dimensionless coefficient which characterises the influence of the admitted approach (deterministic, uniform, triangular or normal distribution) on the required additional reduction of emission $\delta_\alpha$. The dependence of $\delta_\alpha / v$ on $\alpha$ is shown in Fig. 2. Taking the values of $v$ for different countries from Table 1 (Total

Uncertainty) we can calculate the values of $\delta_\alpha$ and the new reduction commitments $\delta+\delta_\alpha$. They are presented in Table 2 for $\alpha = 0.1$ and $\alpha = 0.3$.

**Table 2**. Comparison of new reduction commitments for countries from Table 1, [%].

| Country | original commit-ments | new commitments | | | | | |
|---|---|---|---|---|---|---|---|
| | | $\alpha = 0.1$ | | | $\alpha = 0.3$ | | |
| | | interval | uniform | normal | interval | uniform | normal |
| AT | 8 | 27.2 | 21.2 | 18.9 | 17.6 | 13.4 | 12.4 |
| | | 23.7 | 18.8 | 16.9 | 15.8 | 12.4 | 11.6 |
| | | 32.0 | 24.5 | 21.7 | 20.0 | 14.8 | 13.6 |
| | | 20.0 | 16.3 | 14.8 | 14.0 | 11.4 | 10.8 |
| NL | 8 | 15.0 | 12.8 | 12.0 | 11.5 | 10.0 | 9.6 |
| NO | -1 | 32.6 | 22.1 | 18.1 | 15.8 | 8.5 | 6.8 |
| PL | 6 | 15.6 | 12.6 | 11.5 | 10.8 | 8.7 | 8.2 |
| RU | 0 | 27.2 | 18.7 | 15.5 | 13.6 | 7.7 | 6.3 |
| UK | 8 | 75.2 | 54.2 | 46.2 | 41.6 | 26.9 | 23.5 |
| | | 38.4 | 28.9 | 25.3 | 23.2 | 16.6 | 15.0 |

The shift of the target level is smaller in the stochastic case. Further reduction of the shift will be obtained in the latter case if the variables $\hat{x}_0$ and $\hat{x}(T_i)$ are positively correlated. If we assume that $x_0$ is known exactly, then the uncertainties in both approaches have similar magnitudes.

## 3. Effective emission in trading

### 3.1. Interval uncertainty

The proposed methodology of verification of the Kyoto obligations will influence the conditions of emission trading. Let us consider two countries: a country emitting $x_1(T_i)$ units of the $CO_2$eq with the interval uncertainty $\Delta_i^1$ wishing to buy $E$ units of the excess reduction from another country which is emitting $x_2(T_i)$ units of the $CO_2$eq with the interval uncertainty $\Delta_i^2$. That is, it holds

$$\left|x_1(T_i) - \hat{x}_1(T_i)\right| \le \Delta_i^1, \qquad \left|E - \hat{E}\right| \le r\Delta_i^2, \qquad r = \frac{\hat{E}}{\hat{x}_2(T_i)}$$

Let us notice that the uncertainty is generally given as a fraction of the emission, in percent, i.e. we know rather $r$ than $\Delta_i^2$.

The corrected emission of the country 1 after purchasing $\hat{E}$ saved units will be $\hat{x}_1(T_i) - \hat{E}$. However, its uncertainty should include also this of the purchased quantity. According to the rules of interval calculus this corrected uncertainty is equal to

$$\Delta_i^1 + (1-\delta)\Delta_0^1 + r\Delta_i^2$$

For the original emission, before purchasing, the following inequality was to be satisfied

$$\hat{x}_1(T_i) + (1-2\alpha)[\Delta_i^1 + (1-\delta)\Delta_0^1] \le \hat{x}_0(1-\delta) \tag{9}$$

After the purchase it is changed to

$$\hat{x}_1(T_i) - \hat{E} + (1-2\alpha)[\Delta_i^1 + r\Delta_i^2 + (1-\delta)\Delta_0^1] \le \hat{x}_0(1-\delta) \tag{10}$$

Comparing (9) and (10) we see that they differ each other with the following component, called *the effective excess reduction*

$$E_{eff} = \hat{E} - (1-2\alpha)r\Delta_i^2 = \hat{E}[1-(1-2\alpha)v_2], \qquad v_2 = \frac{\Delta_i^2}{\hat{x}_2(T_i)} \tag{11}$$

where $v_2$ is the relative uncertainty of the country 2. The buying country 1 will be willing to pay rather for the effective excess reduction $E_{eff}$ than for the direct excess reduction $\hat{E}$. However, $E_{eff} < \hat{E}$ if only $\alpha < 0.5$. To make the effective excess reduction "symmetric", it might be advantageous to relate this value to some "reference" uncertainty. For this, we introduce reference relative uncertainty $v_s$ ( $v_s = \Delta_s / \hat{x}(T_i)$ where $\Delta_s$ is the reference interval uncertainty). Thus, (11) is modified as follows

$$E_{tr} = \hat{E}[1-(1-2\alpha)(v_2 - v_s)] \tag{12}$$

which will be called *the effective excess reduction for trading*. This value may form a basis for financial liabilities among countries. Effective excess reductions for trading for the countries from Table 1 with $\alpha = 0.1$ and $\alpha = 0.3$ and the reference uncertainty 10% are depicted in Table 4.

### 3.2 Stochastic uncertainty

To fulfil the obligations, the original emission of the country 1 should satisfy the following condition

$$\hat{x}_1(T_i) + q_{1-\alpha}\sigma_{\hat{x}_1} \le \hat{x}_0(1-\delta)$$

where $\sigma_{\hat{x}_1}$ is given by (6). After purchasing $\hat{E}$ excess reduction units from the country 2 the total variance of the difference $\hat{x}_0(1-\delta) - [x_1(T_i) - \hat{E}]$ is

$$\sigma_{\hat{x}_1}^2 + r^2\sigma_{\hat{x}_2}^2(T_i)$$

where, as before, $r = \hat{E} / \hat{x}_2(T_i)$, and we assumed that both variables $\hat{x}_1$ and $\hat{x}_2$ are uncorrelated. Thus, the new condition will be

$$\hat{x}_1(T_i) - \hat{E} + q_{1-\alpha}\sqrt{\sigma^2_{\hat{x}_1} + r^2\sigma^2_{\hat{x}_2}(T_i)} \le \hat{x}_0(1-\delta)$$

After appropriate simplifications the analogue of (11) can be expressed in the form

$$E_{eff} = \hat{E}(1 - q_{1-\alpha}v_2) \qquad \text{for } \rho_{0i} = 1$$

$$E_{eff} = \hat{E}(1 - \frac{q_{1-\alpha}R}{2\sqrt{2(1-\rho_{0i})}}\frac{v_2}{v_1}v_2) \qquad \text{for } \rho_{0i} << 1$$

where $v_1 = \sigma_{\hat{x}_1}(T_i)/\hat{x}_1(T_i)$, $v_2 = \sigma_{\hat{x}_2}(T_i)/\hat{x}_2(T_i)$, $v_{10} = \sigma_{\hat{x}_1}(0)/\hat{x}_1(T_i)$ are the appropriate relative uncertainties. Moreover $R = \hat{E} / \hat{x}_1(T_i)$ is the purchased fraction of emission of the country 1. Now, the effective excess reduction depends on the uncertainty ratios of both countries and, moreover, on the purchased fraction *R*. This is why we call *it the effective excess reduction of the country 2 for the country 1*.

**Table 4**. Effective excess reductions for trading $E_{tr}$ in percent of the original emission $\hat{E}$ for countries from Table 1, $v_s$ = 0.1 (10%).

Coun-try
Uncert-ainty
$E_{tr} / \hat{E}$ [%]

[%]
α=0.1
α=0.3

AT
12
98.4
98.8

9.8
100.2

**Table 5**. Effective excess reductions for trade $E_{tr}$ in percents of the original emissions $\hat{E}$ in cases when Poland and Russia are offering the excess reduction for sale to countries from Table 1, $v_s$ = 0.1 (10%), $R$ = 0.1 (10%), normal distribution, uncorrelated case.

$E_{tr} / \hat{E}$ [%]

Coun-try
Uncert-ainty
Poland
Russia

[%]
α=0.1
α=0.3
α=0.1
α=0.3

100.1

15
96.0
97.0

7.5
102.0
101.5

NL
4.4
104.5
103.4

NO
21
91.2
93.4

PL
6
103.2
102.4

RU
17
94.4
95.8

UK
42
74.4
80.8

19
92.8
94.6

AT
12
100.58
100.13
98.84
99.74

9,8
100.52
100.12
98.40
99.64

15
100.62
100.14
99.24
99.83

7,5
100.43
100.10
97.65
99.47

NL
4,4
100.15
100.03
95.42
98.97

NO
21
100.68
100.15
99.69
99.93

PL
6

96.86
99.29

RU
17
100.65
100.15

UK
42
100.75
100.17
100.26
100.06

19
100.67
100.15
99.57
99.90

If we want to refer to the reference uncertainty ratio $v_s$, then *the effective excess reduction for trading between two countries* 1 and 2 for $\rho_{0i} << 1$ is

$$E_{tr} = \hat{E}\left(1 - \frac{q_{1-\alpha}R}{2\sqrt{2(1-\rho_{0i})}}\left(\frac{v_2}{v_1}v_2 - v_s\right)\right) \tag{13}$$

In Table 5 the values of $E_{tr} / \hat{E}$ are presented for two countries: Poland and Russia, both offering their excess reductions for sale. The effective excess reduction for Poland is bigger than 100% because Poland has smaller relative uncertainty error (6%) than the reference one (admitted as 10%). On the other way, Russia has rather big relative uncertainty error (17%) and its effective excess reductions are almost always smaller than 100%, dropping to even less than 95.5% for $\alpha = 0.1$.

## 4. Conclusions

In the paper the problem of verification of the Kyoto obligations is discussed. The present knowledge makes it obvious to us that verification of the obligations cannot be done when uncertainty of the reported values is not taken into account. This paper addresses this problem and proposition of a solution is given.

The main idea of our proposition concentrates in replacing the reduction rate by a combination of the reduction and uncertainty. The exact proportions are related with the risk that the real emission has not satisfied the obligations.

Two basic ways of modelling the uncertainty: the deterministic and the stochastic are considered. The deterministic case is easier to manipulate with. The stochastic case involves much more complicated formulae. But it provides much smaller shifts of the original reduction target.

Acceptation of the idea of verification proposed in the paper makes it necessary to change the emission trading rules. When bargaining the price, the buyer should combine the reduction of emission with uncertainty of its reporting, because both of them will count in the final verification of the Kyoto obligations. The paper contains a proposition of solving this problem. Specifically, a construction of an effective excess reduction value, corrected for uncertainty, is proposed as the basis for bargaining the price. The deterministic case provides us with the linear formula, the stochastic one ends with nonlinear formulae, depending also on factors characterising both bargaining parties.

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