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Interim Report **IR-06-053**

Preparatory Signal Detection for the EU-15 Member States Under EU Burden Sharing—Advanced Monitoring Including Uncertainty (1990–2003)

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Approved by

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Beginning with IR-04-024, all monitoring reports follow the same template. This is so that anybody interested in this monitoring exercise can immediately recognize the year-to-year changes in the country assessments. Note that whether or not these changes become visible depends on the assessment itself: We work with relative uncertainty intervals, which prove to be fairly robust as they compensate 'small' changes in the country assessments. The Excel databases, one behind each monitoring report, can be requested free of charge.

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Contents

Abstract

This study follows up IIASA Interim Report IR-04-024 (Jonas *et al.*, 2004a), which addresses the preparatory detection of uncertain greenhouse gas (GHG) emission changes (also termed emission signals) under the Kyoto Protocol. The question probed was *how well do we need to know net emissions if we want to detect a specified emission signal after a given time?* The authors used the Protocol's Annex I countries as net emitters and referred to all Kyoto GHGs (CO_2, CH_4, N_2O, HFCs, PFCs, and SF6) excluding CO_2 emissions/removals due to land-use change and forestry (LUCF). They motivated the application of preparatory signal detection in the context of the Kyoto Protocol as a necessary measure that should have been taken prior to/in negotiating the Protocol. The authors argued that uncertainties are already monitored and are increasingly made available but that monitored emissions and uncertainties are still dealt with in isolation. A connection between emission and (total) uncertainty estimates for the purpose of an advanced country evaluation has not yet been established. The authors developed four preparatory signal detection techniques and applied these to the Annex I countries under the Kyoto Protocol. The frame of reference for preparatory signal detection is that Annex I countries comply with their committed emission targets in 2008–2012. The emissions path between the base year and commitment year/period is generally assumed to be a straight line, and the path of historical emissions is not taken into consideration.

This study applies the strictest of these techniques, the combined undershooting and verification time (Und&VT) concept to advance the monitoring of the GHG emissions reported by the old Member States of the European Union (EU). In contrast to the earlier study, the Member States' committed emission targets under the EU burden sharing in compliance with the Kyoto Protocol are taken into account, however, still assuming that only domestic measures will be used (i.e., excluding Kyoto mechanisms). The Und&VT concept is applied in a standard mode, i.e., with reference to the Member States' committed emission targets in 2008–2012, and in a new mode, i.e., with reference to linear path emission targets between base year and commitment year. Here, the intermediate year of reference is 2003.

To advance the reporting of the EU, uncertainty and its consequences are taken into consideration, i.e., (i) the risk that a Member State's true emissions in the commitment year/period are above its true emission limitation or reduction commitment; and (ii) the detectability of its target. Undershooting the committed EU target or EU-compatible, but detectable, target can decrease this risk. The Member States' linear path undershooting targets for the year 2003 are contrasted with their actual emission situation in that year, for which the distance-to-target indicator (DTI) is employed that has been introduced by the European Environment Agency.

In 2003, only four Member States exhibit a negative DTI and thus appear as potential sellers: France, Germany, Sweden and the United Kingdom. However, expecting that the EU Member States exhibit relative uncertainties in the range of 5–10% and above rather than below excluding LUCF and Kyoto mechanisms, the Member States require considerable undershooting of their EU-compatible, but detectable, targets if one wants to keep the said risk low ($\alpha \approx 0.1$). As of 2003, these conditions can only be met by Germany and the United Kingdom, while France and Sweden can only act as potential high-risk sellers ($\alpha \approx 0.5$). The other Member States do not meet their linear path (base year–commitment year) undershooting targets in 2003.

The relative uncertainty, with which countries report their emissions, matters. For instance, with relative uncertainty increasing from 5 to 10%, the linear path 2008/12 emission signal of the EU as a whole (which has jointly approved an 8% emission reduction under the Kyoto Protocol) switches from detectable to non-detectable ($\alpha > 0.5$), indicating that the negotiations for the Kyoto Protocol were imprudent because they did not take uncertainty and its consequences into account.

It is anticipated that the evaluation of emission signals in terms of risk and detectability will become standard practice and that these two qualifiers will be accounted for in pricing GHG emission permits.

Acknowledgments

I would like to thank Matthias Jonas who supervised my work during the summer of 2006 and Mykola Gusti both of the Forestry Program for many useful discussions, comments and guidance. I would also like to thank the YSSP team (Joanne Bayer, Tanja Huber, Barbara Hauser and Serge Medow) and all of the participants in YSSP 2006 for making my stay at IIASA pleasurable.

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Andriy Bun graduated from Lviv National Polytechnic University, Ukraine, with B.Sc in Applied Mathematics in 2005. He is currently a Master's degree student at the same university. This study is the result of the author's participation in IIASA's 2006 Young Scientist Summer Program. The author was supervised by Matthias Jonas of the Forestry Program.

Preparatory Signal Detection for the EU-15 Member States Under EU Burden Sharing—Advanced Monitoring Including Uncertainty (1990–2003)

Andriy Bun and Matthias Jonas

1 Background and Objective

This study follows up IIASA Interim Report IR-04-024 (Jonas *et al.*, 2004a). It applies the strictest of the preparatory signal detection techniques developed in this report,[1] the combined undershooting and verification time (Und&VT) concept,[2] to advance the monitoring of the greenhouse gas (GHG) emissions reported by the old Member States of the European Union (EU) under EU burden sharing in compliance with the Kyoto Protocol. Here, 'emissions' refer to all Kyoto GHGs (CO_2, CH_4, N_2O, HFCs, PFCs, and SF6) excluding CO_2 emissions/removals due to land-use change and forestry (LUCF). The Member States' emissions are evaluated in relation to the EU's linear target as of 2003 and in terms of their positive and negative contributions to this target.[3] This monitoring process is illustrated in Figures 1 and 2 and Table 1. The figures and the table provide details, for each Member State and the EU-15 as a whole, of trends in emissions of GHGs up to 2003. Figure 1 follows the total emissions of the EU over time since 1990, while the distance-to-target indicator (DTI) introduced in Figure 2, based on the country data listed in Table 1, is a measure of the derivation of actual GHG emissions in 2003 from the linear target path between 1990 and the respective Member State target for 2008–2012, assuming that only domestic measures will be used (i.e., excluding Kyoto mechanisms). A negative DTI means that a Member State is below its

[1] Preparatory signal detection allows generating useful information beforehand as to how great uncertainties can be depending on the level of confidence of the emission signal or the signal one wishes to detect and the risk one is willing to tolerate in not meeting an agreed emission limitation or reduction commitment. It is this knowledge of the required quality of reporting versus uncertainty that one wishes to have at hand before negotiating international environmental treaties such as the Kyoto Protocol. It is generally assumed that the emissions path between the base year and commitment year/period is a straight line, and the path of historical emissions is not taken into consideration.

[2] The term 'verification time' was first used by Jonas *et al.* (1999) and by other authors since then. Actually, a more correct term is 'detection time'. The detection of emission changes does not imply the verification of emissions. The implicit thinking behind the continued use of 'verification time' is that signal detection should, in the long-term, go hand-in-hand with bottom-up/top-down verification (see Jonas *et al.*, 2004a: Section 2.3).

[3] Recent evaluations in relation to the EU's linear targets as of 2001 and 2002 are presented in Jonas *et al.* (2004b,c). However, only the 2003 evaluation has been expanded to also include the new Member States of the EU (Bun, 2006).

linear target path, a positive DTI that a Member State is above its linear target path (EEA, 2005b: Figure 4.2 in combination with Table 10; cf. also EEA, 2005a: Tables ES.6 and 2.6).[4] As Figures 1 and 2 only present relative information of the kind 'must buy versus can sell', Figure 3 is added, which translates this information into absolute numbers based on the Member States' emission changes as of 2003 and their linear targets for that year (Table 1). Figure 3 helps us to understand the 2003 situation of the EU in quantitative terms.

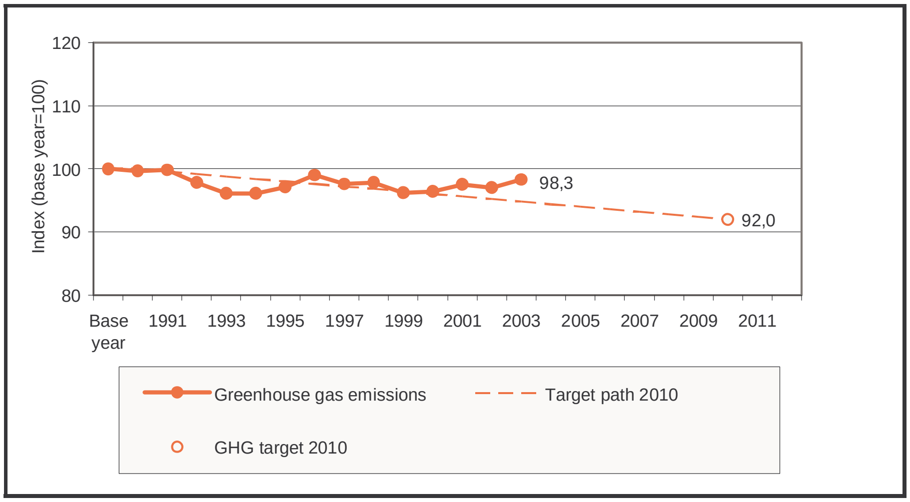

Figure 1: EU-15 GHG emissions for 1990–2003 and linear target path 1990–2008/12 (excluding LUCF and Kyoto mechanisms). Source: EEA (2005a: Figures ES.2 and 2.2); original from Ritter (2006).

The overall objective of the study is to advance the reporting of the EU by taking uncertainty and its consequences into consideration, i.e., (i) the risk that a Member State's true emissions in the commitment year/period are above its true emission limitation or reduction commitment (what we call the true EU reference line); and (ii) the detectability of its target. Undershooting the committed EU target or EU-compatible, but detectable, target can decrease the risk that the Member State's true emissions in the commitment year are above its true EU reference line. Here, the intermediate year of reference in the focus of attention is 2003, i.e., the linear target path 1990–2008/12 is evaluated with respect to this year.

Uncertainties are extracted from the national inventory reports of the Member States and are monitored separately. However, a connection between emission and (total) uncertainty estimates for the purpose of an advanced country evaluation has not yet been established. A recent compilation of uncertainties has been presented by EEA (2005a: Table 1.9; cf. Table 2 below, which was taken from the revised final version of

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[4] For example, Ireland is allowed a 13% increase from 1990 levels by 2008–2012, so its theoretical linear target for 2003 is a rise of no more than 8.5%. Its actual emissions in 2003 show an increase of 25.2% since 1990; hence, its DTI is 25.2 – 8.5, or 16.7 percentage points. Germany's Kyoto target is a 21% reduction, so its theoretical linear target for 2003 is a decrease of 13.7%. Actual emissions in 2003 were 18.5% lower than in 1990; hence, Germany's DTI is (–18.5) – (–13.7), or –4.8 percentage points.

this report available at http://www.foeeurope.org/climate/EUemissionsReport2005.doc). This compilation makes available quantified uncertainty estimates from twelve of the old Member States (extracted from their National Inventory Reports 2004 and 2005), covering 97.8% of the EU-15 GHG emissions in 2003. From the remaining Member States, either a national inventory report was available, which did not include a quantitative uncertainty analysis (Portugal), or no national inventory report was available at all (Luxembourg). The uncertainties refer to a 95% confidence interval[5] and neglect, with the exception of France, the Netherlands and United Kingdom, emissions/removals due to land-use change and forestry (LUCF).

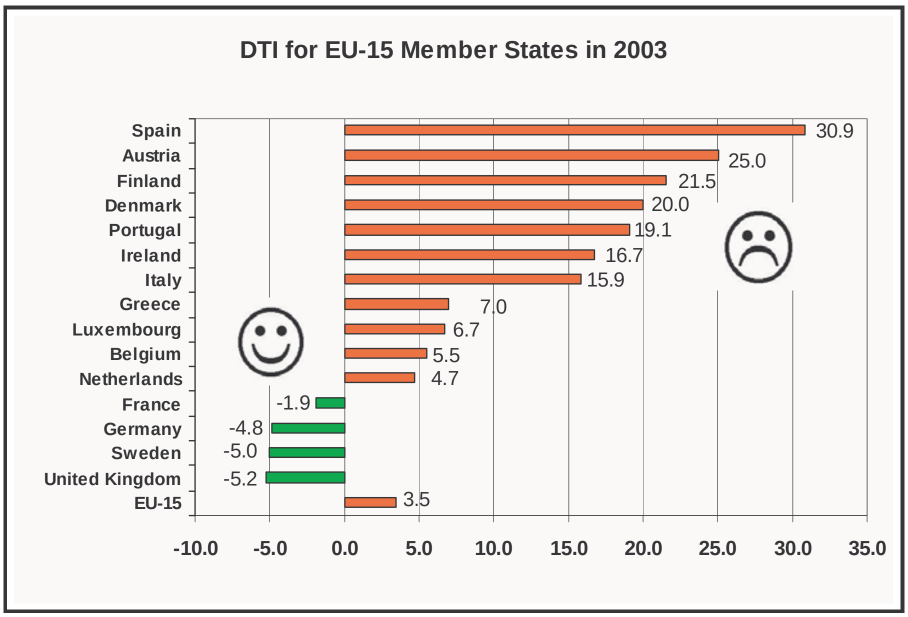

Figure 2: Distance-to-target indicator (DTI) for EU-15 Member States in 2003 in consideration of the EU burden sharing targets under the Kyoto Protocol (excluding LUCF and Kyoto mechanisms).

Taking uncertainty into account in combination with undershooting is important because the amount, by which a Member State undershoots its EU target or its EU-compatible, but detectable, target, can be traded. Towards installing a successful trading regime, Member States may want to price the risk associated with this amount. We anticipate that the evaluation of emission signals in terms of risk and detectability will become standard practice.

Section 2 recalls the methodology of the Und&VT concept, which is applied in Section 3 with the above objective in mind. Results and conclusions are presented in Section 4.

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[5] The Intergovernmental Panel on Climate Change (IPCC) Good Practice Guidelines suggest the use of a 95% confidence interval, which is the interval, which has a 95% probability of containing the unknown true emission value in the absence of biases (and which is equal to approximately two standard deviations if the emission values are normally distributed) (Penman *et al.*, 2000: p. 6.6).

Table 1: Base year and 2003 GHG emissions (in CO_2-equivalents; excluding LUCF and Kyoto mechanisms), 2002–2003 emission changes and 2008–2012 targets (in %) for EU-15 Member States under the Kyoto Protocol and EU burden sharing. Source: EEA (2005a: Tables ES.6 and 2.6) reproduced; original data from Ritter (2006).

Member State	Base Year[a] (million tonnes)	2003 (million tonnes)	Change 2002–2003 (%)	Change Base Year–2003 (%)	Targets 2008–12 under EU burden sharing (%)
Austria	78.5	91.6	5.9	16.6	-13.0
Belgium	146.8	147.7	1.6	0.6	-7.5
Denmark	69.6	74.0	5.3	6.3	-21.0
Finland	70.4	85.5	1.8	21.5	0.0
France	568.0	557.2	7.3	-1.9	0.0
Germany	1248.3	1017.5	9.7	-18.5	-21.0
Greece	111.7	137.6	10.8	23.2	25.0
Ireland	54.0	67.6	0.7	25.2	13.0
Italy	510.3	569.8	0.2	11.6	-6.5
Luxembourg	12.7	11.3	3.1	-11.5	-28.0
Netherlands	213.1	214.8	3.0	0.8	-6.0
Portugal	59.4	81.2	-2.6	36.7	27.0
Spain	286.1	402.3	2.7	40.6	15.0
Sweden	72.3	70.6	-0.9	-2.4	4.0
United Kingdom	751.4	651.1	-12.1	-13.3	-12.5
EU-15	4252.5	4179.6	4.3	-1.7	-8.0

[a] The base year for CO_2, CH_4 and N_2O is 1990. For the fluorinated gases 13 Member States selected 1995 as base year, whereas Finland and France selected 1990. As the EUC inventory is the sum of Member States' inventories, the EU base year estimates for fluorinated gas emissions are the sum of 1995 emissions for 13 Member States and 1990 emissions for Finland and France.

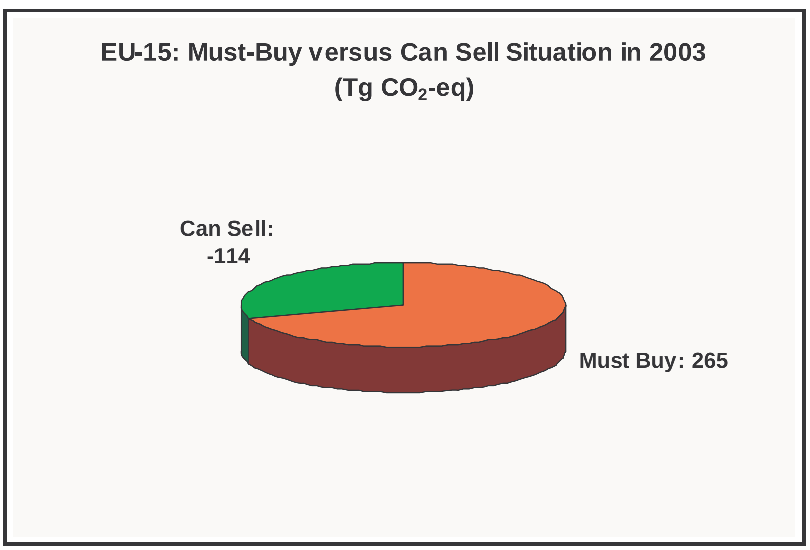

Figure 3: Figure 2 presented in absolute terms. Potential buyers in 2003: AT, BE, DK, ES, FI, GR, IE, IT, LU, NL, PT; potential sellers in 2003: DE, FR, SE, UK. See ISO Country Code for country abbreviations and text for underlying assumptions.

Table 2: Uncertainty estimates available from EU-15 Member States excluding LUCF (with the exception of France, the Netherlands and United Kingdom) and Kyoto mechanisms.[6] Source: http://www.foeeurope.org/climate/EUemissionsReport2005.doc.

Member State	Austria		Belgium		Czech Republic		Croatia		Denmark		Finland	France		Germany	
Citation	Austrian NIR 2005, p. 25-39		Belgian NIR 2005, p. 13-19		Czech NIR 2004, p. 16-17		Croatian NIR 2005, p. 4-5		Danish NIR 2005 p. 34-36		Finnish NIR 2005 p. 24 A-D)	French NIR 2003 p. 30-31		German NIR 2005, p. 1-33-36, Annex 7	
Method used	Tier 1, Tier 2		Tier 1		Tier 1		Tier 1		Tier 1		Tier 1, Tier 2	Tier 1		Tier 1	
Documentation available in NIR (according to Table 6.1 of GPG)	Partially (Table 7)		Yes (provided as a separate table)		Yes: Table 1.3		Yes: Annex 3 (Table A3-1)		Partially: Table 1.4		Yes: Annex 1 (Table A	Yes: Annex 2 (no reference source information)		Yes: Annex [Anhang] 7 (not according to Table 6.1 of GPG)	
Years and sectors included	Tier 1: base year and 1995 - Key sources Tier 2: 1990, 1997 (from year 1999) – All sectors		2001-All sectors except LULUCF; for Flanders, a complete uncertainty study was conducted both on Tier 1 and Tier 2 level		1990, 2001 - All sources (key sources and "others"		1990, 2001 - All Sectors (except LULUCF)		1990, 2003 - The sources included in the uncertainty estimate cover 99.7% of the total Danish greenhouse gas emission (CO2 eq., without CO2 from LUCF).		1990, 2003 – All secto	1990, 2002 (from year 2004) – All sources (key sources and "others")		1990, 2002 - nearly complete estimation for sources 1A, 2A1, 2A2, 2C1, 2C3, 4A(2002 only), 5A(2002 only)	
Uncertainty (%)	Tier 1	Tier 2	Tier 1	Tier 2	Tier 1	Tier 2	Tier 1	Tier 2	Tier 1	Tier 2	Tier 1	Tier 1	Tier 2	Tier 1	Tier 2
CO_2	Base year: 2,5% 1995: 2,0%	1990: 2,3% 1997: 2,1	3,6%	-					2,5%		+/- 15% (with LULUCF) +/- 2% (without LULUCF)	-	-	-	-
CH_4	Base year: 19,1% 1995: 20,3%	1990: 48,3% 1997: 47,4%	24,0%	-					20%		+/- 20%	-	-	-	-
N_2O	Base year: 104,3% 1995: 101,2%	1990: 89,6% 1997: 85,9%	91,0%	-					57%		-40 to +100%	-	-	-	-
F-gases	-	-	-	-					129%		-10 to +20%	-	-	-	-
Total	Base year: 4,1% 1995: 5,5%	1990: 9,8% 1997: 8,9%	8,1%	-	7,0%		36,1%		6,8%		+/- 16% (with LULUCF)	22,1	-	-	-
Uncertainty in trend (%)	Tier 1	Tier 2	Tier 1	Tier 2	Tier 1	Tier 2	Tier 1	Tier 2	Tier 1	Tier 2	Tier 1	Tier 1	Tier 2	Tier 1	Tier 2
CO_2	-	-	-	-					1,9%		-	-	-	-	-
CH_4	-	-	-	-					9,3%		-	-	-	-	-
N_2O	-	-	-	-					14%		-	-	-	-	-
F-gases	-	-	-	-					54%		-	-	-	-	-
Total	-	-	3,8%	-	2,9%		6,7%		2,1%		+/- 19% (with LULUCF)	3,5	-	-	-

[6] Austria has, as the only EU-25 Member State, carried out Full Carbon Accounting (FCA) for 1990. Jonas and Nilsson (2001: Table 14) constructed a full carbon account, which serves as a basis for extracting a partial carbon account that is extended by CH_4 and N_2O and that is in line with the IPCC Guidelines (IPCC, 1997a,b,c). The respective relative uncertainties (more exactly: the median values of the respective relative uncertainty classes) are 2.5% for CO_2; 30% for CH_4; >40% for N_2O; and 7.5% for $CO_2 + CH_4 + N_2O$.

Table 2: continued.

Member State	**Greece**		**Ireland**		**Italy**		**Netherlands**		**Slovakia**		**Spain**		**Sweden**		**United Kingdom**	
Citation	Greek NIR 2005, p. 18-20. Annex IV, Table IV.1		Irish NIR 2005, p. 8-9, 14-15 (Tab. 1.4)		Italian NIR 2004, p. 18, Annex 1		Dutch NIR 2005, p. 1-23 to 1-26, Annex 1.2		Slovakian NIR 2005, p. 12-13; Coverletter 2005 (Data of greenhouse gas emissions): Table on Tier 1 uncertainty calculation and reporting		Spanish NIR 2005, p.46-55		Swedish NIR 2005, p. 16-20		UK NIR 2004 (draft) Annex 7, Table A7.4	
Method used	Tier 1		Tier 1		Tier 1		Tier 1		Tier 1		Tier 1		Tier 1		Tier 1, Tier 2	
Documentation available in NIR (according to Table 6.1 of GPG)	Yes. Annex IV.1		Yes: Table 1.4		Yes (Table A1.2)		Partially (Table 1.4)		Yes: Table on Tier 1 uncertainty calculation and reporting		Yes: Table 5.5.2 and 5.5.3		Partially (Annex 2)		Yes: Annex 7 (no composite table on references included)	
Years and sectors included	1990, 2003 - All sources		1990, 2003 – All sources		1990, 2002 – All sources		1990/95, 2003 – All sources		1990, 2003 - All sources		2001, 2002 (from year 2005) - All sources (key sources and "other emission sources")		2003 (from year 2005) - All sources		1990, 2002 (from year 2004) – All sources	
Uncertainty (%)	Tier 1	Tier 2	Tier 1	Tier 2	Tier 1	Tier 2	Tier 1	Tier 2	Tier 1	Tier 2	Tier 1	Tier 2	Tier 1	Tier 2	Tier 1	Tier 2
CO_2	3,7% (witout LULUCF) 5% (with LULUCF)	-	1,4	-	-	-	+/-5%	-			-	-	3,5	-	-	2,1
CH_4	34,4%	-	3,5	-	-	-	+/-25%	-			-	-	1,66	-	-	13
N_2O	104,1%	-	11,6	-	-	-	+/-50%	-			-	-	5,99	-	-	231
F-gases	69,9%	-	0,2	-	-	-	HFC+/-50% PFCs +/-50% SF6 +/-50%	-				-	0,31	-	-	HFC 25 PFCs 19 SF6 13
Total	10,8% (without LUCF) 11,5% (with LULUCF)	-	12,2	-	2,5%	-	6%	-	10,0%		2001 +/- 17% 2002 +/- 15.8%	-	6,93	-	17,9	15
Uncertainty in trend (%)	Tier 1	Tier 2	Tier 1	Tier 2	Tier 1	Tier 2	Tier 1	Tier 2	Tier 1	Tier 2	Tier 1	Tier 2	Tier 1	Tier 2	Tier 1	Tier 2
CO_2	-	-	2,2	-	-	-	5%	-			-	-	-	-	-	-
CH_4	-	-	2,5	-	-	-	6%	-			-	-	-	-	-	-
N_2O	-	-	7,0	-	-	-	15%	-			-	-	-	-	-	-
F-gases	-	-	0,2	-	-	-	7%	-			-	-	-	-	-	-
Total	8%	-	7,7	-	2,4%	-	4%	-	3,2%		2001 +/-2.65% 2002 +/-3.95%	-	-	-	2	-

2 Methodology

The applied Und&VT concept is described in detail in Jonas *et al.* (2004a). With the help of δ_{KP}, the normalized emission change under the EU burden sharing in compliance with the Kyoto Protocol,[7] and δ_{crit}, the critical (crit) emission limitation or reduction target, the four cases listed in Table 3 and shown in Figure 4 are distinguished. The Member States' δ_{crit} values can be determined knowing the relative (total) uncertainty (ρ) of their net emissions (see equation (32a,b) in Jonas *et al.*, 2004a):

$$\delta_{\mathrm{crit}} = \begin{cases} \dfrac{\rho}{1+\rho} & \mathrm{x}_2 < \mathrm{x}_1 \ \left(\delta_{\mathrm{KP}} > 0\right) \\ & \text{for} \\ -\dfrac{\rho}{1-\rho} & \mathrm{x}_2 \geq \mathrm{x}_1 \ \left(\delta_{\mathrm{KP}} \leq 0\right) \end{cases} , \qquad \text{(1a,b)}$$

where ρ is assumed to be symmetrical and, in line with preparatory signal detection, constant over time, i.e., $\rho\left(\mathrm{t}_1\right) = \rho\left(\mathrm{t}_2\right)$ with t_1 referring to the base year 1990[8] and t_2 to the commitment year 2010 (as the temporal mean of the commitment period 2008–2012). The Member States' best estimates of their emissions at t_i are denoted by x_i.

Table 4 assembles the nomenclature that is required for recalling Cases 1–4.

Table 3: The four cases that are distinguished in applying the Und&VT concept (see also Figure 4).

Emission Reduction: $\delta_{\mathrm{KP}} > 0$	**Case 1**	$\delta_{\mathrm{crit}} \leq \delta_{\mathrm{KP}}$	Detectable EU/Kyoto target	
	Case 2	$\delta_{\mathrm{crit}} > \delta_{\mathrm{KP}}$	Non-detectable EU/Kyoto target: An initial or obligatory undershooting is applied so that the Member States' emission signals become detectable (before the Member States are permitted to make economic use of excess emission reductions)	
Emission Limitation: $\delta_{\mathrm{KP}} \leq 0$	**Case 3**	$\delta_{\mathrm{crit}} < \delta_{\mathrm{KP}}$	Non-detectable EU/Kyoto target	As in Case 2, an initial or obligatory undershooting is applied unconditionally for all Member States (their emission reductions, not increases, must become detectable)
	Case 4	$\delta_{\mathrm{crit}} \geq \delta_{\mathrm{KP}}$	Detectable EU/Kyoto target[a]	

[a] Detectability according to Case 4 differs from detectability according to Case 1. The reason for this is that countries committed to emission reduction ($\delta_{\mathrm{KP}} > 0$) and emission limitation ($\delta_{\mathrm{KP}} \leq 0$) exhibit an over/undershooting dissimilarity (see Jonas *et al.*, 2004a: Sections 3.1 and 3.2 for details).

[7] Here, δ_{KP} specifies the normalized emission changes, to which the Member States committed themselves under the EU burden sharing and which are different from those under the Kyoto Protocol. However, δ_{KP} is continued to be used to avoid additional indexing.

[8] The base year selected is 1990 because it is determined by the 'CO_2-CH_4-N_2O system of gases' (see Jonas *et al.*, 2004a: Section 3).

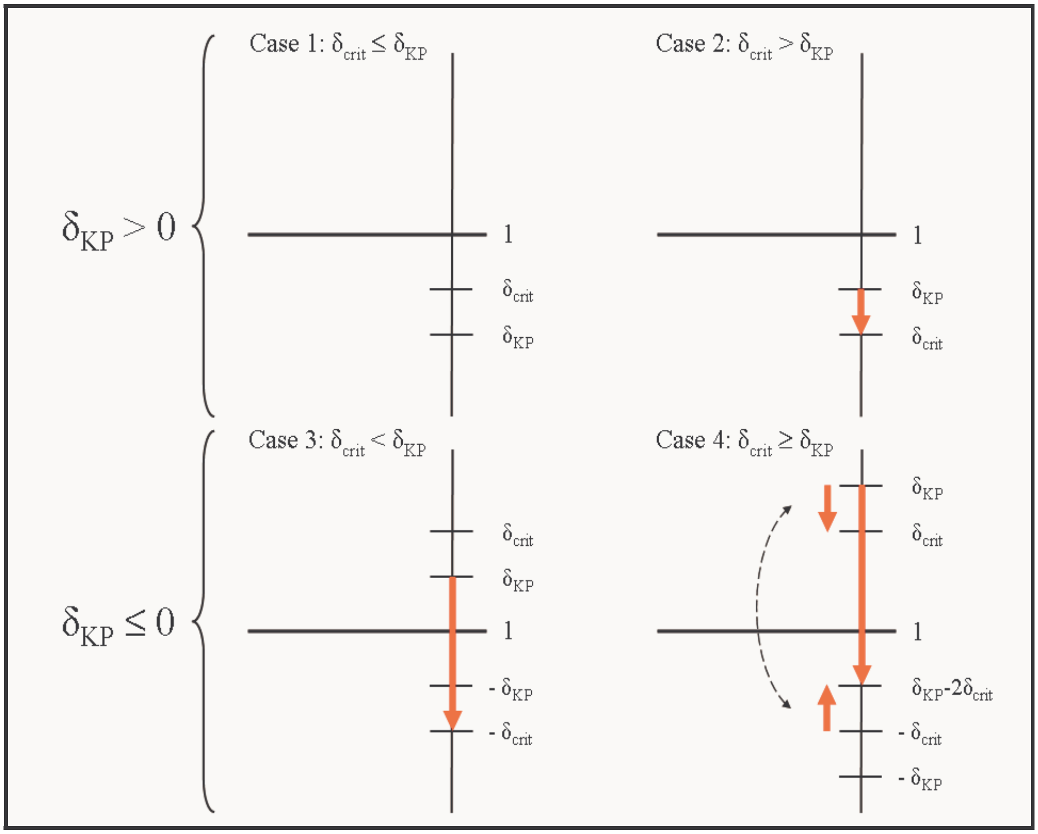

Figure 4: The four cases that are distinguished in applying the Und&VT concept (see also Table 3). Emission reduction: $\delta_{KP} > 0$; emission limitation: $\delta_{KP} \leq 0$.

<u>*Case 1: $\delta_{KP} > 0$: $\delta_{crit} \leq \delta_{KP}$.*</u> Here, use is made of equations (43a), (B1), (D1), (B3) and (D2) of Jonas *et al.* (2004a: Appendix D):

$$\frac{x_2}{x_1} \leq (1-\delta_{KP})\frac{1}{1+(1-2\alpha)\rho} = 1-\delta_{mod} \ , \qquad (2), (3)$$

where

$$\delta_{mod} = 1-(1-\delta_{KP})\frac{1}{1+(1-2\alpha)\rho} = \delta_{KP} + U \qquad (4), (5)$$

$$U = (1-\delta_{KP})\frac{(1-2\alpha)\rho}{1+(1-2\alpha)\rho} \ . \qquad (6)$$

<u>*Case 2: $\delta_{KP} > 0$: $\delta_{crit} > \delta_{KP}$.*</u> Here, use is made of equations (45a), (B1), (D3a,b), (D4) and (42b) of Jonas *et al.* (2004a: Appendix D):

$$\frac{x_2}{x_1} \le \left(1-\delta_{crit}\right)\frac{1}{1+\left(1-2\alpha\right)\rho} = 1-\delta_{mod} \ , \qquad (7), (3)$$

where

$$\delta_{mod} = 1-\left(1-\delta_{crit}\right)\frac{1}{1+\left(1-2\alpha\right)\rho} = \delta_{KP} + U \qquad (8), (5)$$

$$U = U_{Gap} + \left(1-\delta_{crit}\right)\frac{\left(1-2\alpha\right)\rho}{1+\left(1-2\alpha\right)\rho} \qquad (9)$$

with

$$U_{Gap} = \delta_{crit} - \delta_{KP} \ . \qquad (10)$$

Table 4: Nomenclature for Cases 1–4.

Known or Prescribed:	
x_i	A Member State's net emissions (best estimate) at t_i
α	The risk that a Member State's true emissions in the commitment year/period are above its true emission limitation or reduction commitment (true EU reference line) Note: In Jonas *et al.* (2004a: Section 3.4 and Appendix D) α is replaced by α_v (where 'v' refers to 'verifiable') in Cases 2–4, which is not done here
δ_{KP}	A Member State's normalized emission change committed under the EU burden sharing in compliance with the Kyoto Protocol
ρ	The relative (total) uncertainty of a Member State's net emissions
Derived:	
U	Undershooting Note: In Jonas *et al.* (2004a: Section 3.4 and Appendix D) U is replaced by U_v (where 'v' refers to 'verifiable') in Cases 2–4, which is not done here
U_{Gap}	Initial or obligatory undershooting
δ_{crit}	A Member State's critical emission limitation or reduction target or, equivalently, its reference line for undershooting (Case 2: δ_{crit}; Case 3: $-\delta_{crit}$; Case 4: $-\delta'_{crit} = \delta_{KP} - 2\delta_{crit}$)
δ_{mod}	A Member State's modified emission limitation or reduction target
Unknown:	
$x_{t,i}$	A Member State's true emissions at t_i Although true emissions are unknown, the risk α can be grasped that $x_{t,2}$ is $\ge$ the true EU reference line (which is given, e.g., by $\left(1-\delta_{KP}\right)x_{t,1}$ in Case 1)

Case 3: $\delta_{KP} \leq 0$: $\delta_{crit} < \delta_{KP}$. Here, use is made of equations (50a), (B1), (D7a,b), (D8) and (52) of Jonas *et al.* (2004a: Appendix D):

$$\frac{x_2}{x_1} \leq \left(1+\delta_{\mathrm{crit}}\right)\frac{1}{1+\left(1-2\alpha\right)\rho} = 1-\delta_{\mathrm{mod}} \ , \tag{11), (3}$$

where

$$\delta_{\mathrm{mod}} = 1-\left(1+\delta_{\mathrm{crit}}\right)\frac{1}{1+\left(1-2\alpha\right)\rho} = \delta_{\mathrm{KP}} + \mathrm{U} \tag{12), (5}$$

$$\mathrm{U} = \mathrm{U}_{\mathrm{Gap}} + \left(1+\delta_{\mathrm{crit}}\right)\frac{\left(1-2\alpha\right)\rho}{1+\left(1-2\alpha\right)\rho} \tag{13}$$

with

$$\mathrm{U}_{\mathrm{Gap}} = -\left(\delta_{\mathrm{crit}} + \delta_{\mathrm{KP}}\right) \ . \tag{14}$$

Case 4: $\delta_{KP} \leq 0$: $\delta_{crit} \geq \delta_{KP}$. Here, use is made of equations (55a), (B1), (D11a,b), (D12), (57) and (58) of Jonas *et al.* (2004a: Appendix D):

$$\frac{x_2}{x_1} \leq \left(1+\delta'_{\mathrm{crit}}\right)\frac{1}{1+\left(1-2\alpha\right)\rho} = 1-\delta_{\mathrm{mod}} \ , \tag{15), (3}$$

where

$$\delta_{\mathrm{mod}} = 1-\left(1+\delta'_{\mathrm{crit}}\right)\frac{1}{1+\left(1-2\alpha\right)\rho} = \delta_{\mathrm{KP}} + \mathrm{U} \tag{16), (5}$$

$$\mathrm{U} = \mathrm{U}_{\mathrm{Gap}} + \left(1+\delta'_{\mathrm{crit}}\right)\frac{\left(1-2\alpha\right)\rho}{1+\left(1-2\alpha\right)\rho} \tag{17}$$

with

$$\mathrm{U}_{\mathrm{Gap}} = -2\delta_{\mathrm{crit}} \tag{18}$$

$$-\delta'_{\mathrm{crit}} = \delta_{\mathrm{KP}} - 2\delta_{\mathrm{crit}} \ . \tag{19}$$

It is recalled that emission reductions are measured positively ($\delta_{\mathrm{KP}} > 0$) and emission increases negatively ($\delta_{\mathrm{KP}} < 0$), which is opposite to the emissions reporting for the EU (see Section 1). However, this can be readily rectified by introducing a minus sign when reporting the results.

3 Results

The evaluation procedure encompasses two steps. In the first step the Und&VT concept is applied with reference to the time period base year–commitment year. With the knowledge of ρ, the relative (total) uncertainty with which a Member State reports its net emissions and which is assumed here to take on one of the values listed in Table 5 (excluding LUCF and Kyoto mechanisms), Equation (1) can be used to determine δ_{crit}, the Member State's critical emission limitation or reduction target.

Comparing δ_{crit} and δ_{KP}, the Member States' 2008–12 targets under the EU burden sharing in compliance with the Kyoto Protocol (see Table 1), allows to identify which case applies to which Member State, that is, the conditions that underlie the emissions reporting of a particular Member State (and the EU as the whole) (see Tables 3 and 6).

Table 7 lists the Member States' modified emission limitation or reduction targets δ_{mod} (equations (4), (8), (12) and (16)), where the (Case 1: '$x_{t,2}$-greater-than-$(1-\delta_{\mathrm{KP}})x_{t,1}$'; Cases 2 and 3: '$x_{t,2}$-greater-than-$(1-|\delta_{\mathrm{crit}}|)x_{t,1}$'; Case 4: '$x_{t,2}$-greater-than-$(1-(\delta_{\mathrm{KP}}-2\delta_{\mathrm{crit}}))x_{t,1}$') risk α is specified to be 0, 0.1, …, 0.5. Table 8 lists the undershooting U (Equations (6), (9), (13) and (17)) contained in the modified emission limitation or reduction targets δ_{mod} listed in Table 7.

As explained by Jonas *et al.* (2004a: Section 3.3), it is the sum of δ_{KP} and U, i.e., the modified emission limitation or reduction target δ_{mod} (see Equation (5)) that matters initially because it describes a Member State's overall burden. However, once Member States have agreed upon their δ_{KP} targets, it is the undershooting U which then becomes solely important. Therefore, only U is considered in the 2$^{\mathrm{nd}}$ step of the evaluation, where the focus is on the Member States' emissions as of 2003.

In this second step, the U values reported in Table 8 are multiplied with the factor ($-13/20$). The minus sign ensures compliance with the emissions reporting for the EU, which measures emission reductions negatively and emission increases positively (see Section 1). The factor ($13/20$) establishes the linear path (base year–commitment year) undershooting targets for the year 2003 (see Table 9).

The results are interpreted in Section 4, together with the conclusions that can be drawn from this interpretation.

Table 5: Critical emission limitation or reduction targets (δ_{crit}) for a range of relative uncertainty values (ρ) (according to equation (1), covering the uncertainty estimates available from the EU-15 Member States (confer Table 2).

	$\delta_{KP} > 0$	$\delta_{KP} \leq 0$		$\delta_{KP} > 0$	$\delta_{KP} \leq 0$
ρ %	δ_{crit} %	δ_{crit} %	ρ %	δ_{crit} %	δ_{crit} %
0.0		0.00	15.0	13.04	-17.65
2.5	2.44	-2.56	20.0	16.67	-25.00
5.0	4.76	-5.26	30.0	23.08	-42.86
7.5	6.98	-8.11	40.0	28.57	-66.67
10.0	9.09	-11.11			

Table 6: The conditions (in the form of Cases 1–4) that underlie the emissions reporting of a particular EU-15 Member State (MS) and the EU as a whole. Green: Detectable EU/Kyoto target under emission reduction (Case 1). Orange: Detectable EU/Kyoto target under emission limitation (Case 4). Red: Non-detectable EU/Kyoto Target under emission reduction (Case 2) or emission limitation (Case 3).

MS	δ_{KP} %	**Case Identification for $\rho =$ 0%**	**2.5%**	**5%**	**7.5%**	**10%**	**15%**	**20%**	**30%**	**40%**
AT	**13.0**	Case 1	Case 1	Case 1	Case 1	Case 1	Case 2	Case 2	Case 2	Case 2
BE	**7.5**	Case 1	Case 1	Case 1	Case 1	Case 2	Case 2	Case 2	Case 2	Case 2
DK	**21.0**	Case 1	Case 1	Case 1	Case 1	Case 1	Case 1	Case 1	Case 2	Case 2
FI	**0.0**	Case 4	Case 3	Case 3	Case 3	Case 3	Case 3	Case 3	Case 3	Case 3
FR	**0.0**	Case 4	Case 3	Case 3	Case 3	Case 3	Case 3	Case 3	Case 3	Case 3
DE	**21.0**	Case 1	Case 1	Case 1	Case 1	Case 1	Case 1	Case 1	Case 2	Case 2
GR	**-25.0**	Case 4	Case 4	Case 4	Case 4	Case 4	Case 4	Case 4	Case 3	Case 3
IE	**-13.0**	Case 4	Case 4	Case 4	Case 4	Case 4	Case 3	Case 3	Case 3	Case 3
IT	**6.5**	Case 1	Case 1	Case 1	Case 2	Case 2	Case 2	Case 2	Case 2	Case 2
LU	**28.0**	Case 1	Case 1	Case 1	Case 1	Case 1	Case 1	Case 1	Case 1	Case 2
NL	**6.0**	Case 1	Case 1	Case 1	Case 2	Case 2	Case 2	Case 2	Case 2	Case 2
PT	**-27.0**	Case 4	Case 4	Case 4	Case 4	Case 4	Case 4	Case 4	Case 3	Case 3
ES	**-15.0**	Case 4	Case 4	Case 4	Case 4	Case 4	Case 3	Case 3	Case 3	Case 3
SE	**-4.0**	Case 4	Case 4	Case 3	Case 3	Case 3	Case 3	Case 3	Case 3	Case 3
UK	**12.5**	Case 1	Case 1	Case 1	Case 1	Case 1	Case 2	Case 2	Case 2	Case 2
EU-15	**8.0**	**Case 1**	**Case 1**	**Case 1**	**Case 1**	**Case 2**	**Case 2**	**Case 2**	**Case 2**	**Case 2**

Table 7: The Und&VT concept applied to the EU-15 Member States (MS). The table lists the 2008–2012 modified emission limitation or reduction targets δ_{mod} (equations (4), (8), (12) and (16)), where the (Case 1: '$x_{t,2}$-greater-than-$(1-\delta_{KP})x_{t,1}$'; Cases 2 and 3: $x_{t,2}$-greater-than-$(1-|\delta_{crit}|)x_{t,1}$'; Case 4: '$x_{t,2}$-greater-than-$(1-(\delta_{KP}-2\delta_{crit}))x_{t,1}$') risk α is specified to be 0, 0.1, …, 0.5.

MS	δ_{KP} %	α 1	Modified Emission Limitation or Reduction Target δ_{mod} in % for $\rho =$ 0%	2.5%	5%	7.5%	10%	15%	20%	30%	40%
AT	**13.0**	0.0	13.0	15.1	17.1	19.1	20.9	24.4	30.6	40.8	49.0
		0.1	13.0	14.7	16.3	17.9	19.4	22.4	28.2	38.0	45.9
		0.2	13.0	14.3	15.5	16.7	17.9	20.2	25.6	34.8	42.4
		0.3	13.0	13.9	14.7	15.5	16.3	18.0	22.8	31.3	38.4
		0.4	13.0	13.4	13.9	14.3	14.7	15.6	19.9	27.4	33.9
		0.5	13.0	13.0	13.0	13.0	13.0	13.0	16.7	23.1	28.6
BE	**7.5**	0.0	7.5	9.8	11.9	14.0	17.4	24.4	30.6	40.8	49.0
		0.1	7.5	9.3	11.1	12.7	15.8	22.4	28.2	38.0	45.9
		0.2	7.5	8.9	10.2	11.5	14.2	20.2	25.6	34.8	42.4
		0.3	7.5	8.4	9.3	10.2	12.6	18.0	22.8	31.3	38.4
		0.4	7.5	8.0	8.4	8.9	10.9	15.6	19.9	27.4	33.9
		0.5	7.5	7.5	7.5	7.5	9.1	13.0	16.7	23.1	28.6
DK	**21.0**	0.0	21.0	22.9	24.8	26.5	28.2	31.3	34.2	40.8	49.0
		0.1	21.0	22.5	24.0	25.5	26.9	29.5	31.9	38.0	45.9
		0.2	21.0	22.2	23.3	24.4	25.5	27.5	29.5	34.8	42.4
		0.3	21.0	21.8	22.5	23.3	24.0	25.5	26.9	31.3	38.4
		0.4	21.0	21.4	21.8	22.2	22.5	23.3	24.0	27.4	33.9
		0.5	21.0	21.0	21.0	21.0	21.0	21.0	21.0	23.1	28.6
FI	**0.0**	0.0	0.0	4.9	9.8	14.5	19.2	28.4	37.5	56.0	76.2
		0.1	0.0	4.5	8.9	13.3	17.7	26.5	35.3	53.9	74.7
		0.2	0.0	4.0	8.0	12.1	16.1	24.4	33.0	51.6	73.1
		0.3	0.0	3.5	7.1	10.8	14.5	22.3	30.6	49.0	71.3
		0.4	0.0	3.0	6.2	9.5	12.9	20.0	27.9	46.1	69.1
		0.5	0.0	2.6	5.3	8.1	11.1	17.6	25.0	42.9	66.7
FR	**0.0**	0.0	0.0	4.9	9.8	14.5	19.2	28.4	37.5	56.0	76.2
		0.1	0.0	4.5	8.9	13.3	17.7	26.5	35.3	53.9	74.7
		0.2	0.0	4.0	8.0	12.1	16.1	24.4	33.0	51.6	73.1
		0.3	0.0	3.5	7.1	10.8	14.5	22.3	30.6	49.0	71.3
		0.4	0.0	3.0	6.2	9.5	12.9	20.0	27.9	46.1	69.1
		0.5	0.0	2.6	5.3	8.1	11.1	17.6	25.0	42.9	66.7
DE	**21.0**	0.0	21.0	22.9	24.8	26.5	28.2	31.3	34.2	40.8	49.0
		0.1	21.0	22.5	24.0	25.5	26.9	29.5	31.9	38.0	45.9
		0.2	21.0	22.2	23.3	24.4	25.5	27.5	29.5	34.8	42.4
		0.3	21.0	21.8	22.5	23.3	24.0	25.5	26.9	31.3	38.4
		0.4	21.0	21.4	21.8	22.2	22.5	23.3	24.0	27.4	33.9
		0.5	21.0	21.0	21.0	21.0	21.0	21.0	21.0	23.1	28.6
GR	**-25.0**	0.0	-25.0	-16.9	-9.0	-1.2	6.6	22.0	37.5	56.0	76.2
		0.1	-25.0	-17.5	-10.1	-2.6	4.8	19.9	35.3	53.9	74.7
		0.2	-25.0	-18.1	-11.1	-4.1	3.0	17.7	33.0	51.6	73.1
		0.3	-25.0	-18.7	-12.2	-5.6	1.2	15.4	30.6	49.0	71.3
		0.4	-25.0	-19.3	-13.3	-7.2	-0.8	12.9	27.9	46.1	69.1
		0.5	-25.0	-19.9	-14.5	-8.8	-2.8	10.3	25.0	42.9	66.7

Table 7: continued.

IE	**-13.0**	0.0	-13.0	-5.2	2.4	10.0	17.5	28.4	37.5	56.0	76.2
		0.1	-13.0	-5.8	1.5	8.7	15.9	26.5	35.3	53.9	74.7
		0.2	-13.0	-6.3	0.5	7.4	14.4	24.4	33.0	51.6	73.1
		0.3	-13.0	-6.8	-0.5	6.0	12.7	22.3	30.6	49.0	71.3
		0.4	-13.0	-7.3	-1.5	4.6	11.0	20.0	27.9	46.1	69.1
		0.5	-13.0	-7.9	-2.5	3.2	9.2	17.6	25.0	42.9	66.7
IT	**6.5**	0.0	6.5	8.8	11.0	13.5	17.4	24.4	30.6	40.8	49.0
		0.1	6.5	8.3	10.1	12.2	15.8	22.4	28.2	38.0	45.9
		0.2	6.5	7.9	9.2	11.0	14.2	20.2	25.6	34.8	42.4
		0.3	6.5	7.4	8.3	9.7	12.6	18.0	22.8	31.3	38.4
		0.4	6.5	7.0	7.4	8.4	10.9	15.6	19.9	27.4	33.9
		0.5	6.5	6.5	6.5	7.0	9.1	13.0	16.7	23.1	28.6
LU	**28.0**	0.0	28.0	29.8	31.4	33.0	34.5	37.4	40.0	44.6	49.0
		0.1	28.0	29.4	30.8	32.1	33.3	35.7	37.9	41.9	45.9
		0.2	28.0	29.1	30.1	31.1	32.1	33.9	35.7	39.0	42.4
		0.3	28.0	28.7	29.4	30.1	30.8	32.1	33.3	35.7	38.4
		0.4	28.0	28.4	28.7	29.1	29.4	30.1	30.8	32.1	33.9
		0.5	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.0	28.6
NL	**6.0**	0.0	6.0	8.3	10.5	13.5	17.4	24.4	30.6	40.8	49.0
		0.1	6.0	7.8	9.6	12.2	15.8	22.4	28.2	38.0	45.9
		0.2	6.0	7.4	8.7	11.0	14.2	20.2	25.6	34.8	42.4
		0.3	6.0	6.9	7.8	9.7	12.6	18.0	22.8	31.3	38.4
		0.4	6.0	6.5	6.9	8.4	10.9	15.6	19.9	27.4	33.9
		0.5	6.0	6.0	6.0	7.0	9.1	13.0	16.7	23.1	28.6
PT	**-27.0**	0.0	-27.0	-18.9	-10.9	-3.1	4.7	20.3	35.8	56.0	76.2
		0.1	-27.0	-19.5	-12.0	-4.5	3.0	18.1	33.6	53.9	74.7
		0.2	-27.0	-20.1	-13.1	-6.0	1.2	15.9	31.3	51.6	73.1
		0.3	-27.0	-20.7	-14.2	-7.6	-0.7	13.5	28.7	49.0	71.3
		0.4	-27.0	-21.3	-15.3	-9.1	-2.7	11.0	26.0	46.1	69.1
		0.5	-27.0	-21.9	-16.5	-10.8	-4.8	8.3	23.0	42.9	66.7
ES	**-15.0**	0.0	-15.0	-7.2	0.5	8.1	15.7	28.4	37.5	56.0	76.2
		0.1	-15.0	-7.7	-0.5	6.8	14.1	26.5	35.3	53.9	74.7
		0.2	-15.0	-8.2	-1.4	5.5	12.5	24.4	33.0	51.6	73.1
		0.3	-15.0	-8.8	-2.4	4.1	10.8	22.3	30.6	49.0	71.3
		0.4	-15.0	-9.3	-3.4	2.7	9.0	20.0	27.9	46.1	69.1
		0.5	-15.0	-9.9	-4.5	1.2	7.2	17.6	25.0	42.9	66.7
SE	**-4.0**	0.0	-4.0	3.5	9.8	14.5	19.2	28.4	37.5	56.0	76.2
		0.1	-4.0	3.1	8.9	13.3	17.7	26.5	35.3	53.9	74.7
		0.2	-4.0	2.6	8.0	12.1	16.1	24.4	33.0	51.6	73.1
		0.3	-4.0	2.1	7.1	10.8	14.5	22.3	30.6	49.0	71.3
		0.4	-4.0	1.6	6.2	9.5	12.9	20.0	27.9	46.1	69.1
		0.5	-4.0	1.1	5.3	8.1	11.1	17.6	25.0	42.9	66.7
UK	**12.5**	0.0	12.5	14.6	16.7	18.6	20.5	24.4	30.6	40.8	49.0
		0.1	12.5	14.2	15.9	17.5	19.0	22.4	28.2	38.0	45.9
		0.2	12.5	13.8	15.0	16.3	17.5	20.2	25.6	34.8	42.4
		0.3	12.5	13.4	14.2	15.0	15.9	18.0	22.8	31.3	38.4
		0.4	12.5	12.9	13.4	13.8	14.2	15.6	19.9	27.4	33.9
		0.5	12.5	12.5	12.5	12.5	12.5	13.0	16.7	23.1	28.6
EU-15	**8.0**	**0.0**	**8.0**	**10.2**	**12.4**	**14.4**	**17.4**	**24.4**	**30.6**	**40.8**	**49.0**
		0.1	**8.0**	**9.8**	**11.5**	**13.2**	**15.8**	**22.4**	**28.2**	**38.0**	**45.9**
		0.2	**8.0**	**9.4**	**10.7**	**12.0**	**14.2**	**20.2**	**25.6**	**34.8**	**42.4**
		0.3	**8.0**	**8.9**	**9.8**	**10.7**	**12.6**	**18.0**	**22.8**	**31.3**	**38.4**
		0.4	**8.0**	**8.5**	**8.9**	**9.4**	**10.9**	**15.6**	**19.9**	**27.4**	**33.9**
		0.5	**8.0**	**8.0**	**8.0**	**8.0**	**9.1**	**13.0**	**16.7**	**23.1**	**28.6**

Table 8: The Und&VT concept applied to the EU-15 Member States (MS). The table lists the undershooting U (equations (6), (9), (13) and (17)) contained in the modified emission limitation or reduction targets δ_{mod} listed in Table 7.

MS	δ_{KP} **%**	α **1**	**Undershooting U in % for $\rho =$** 0%	2.5%	5%	7.5%	10%	15%	20%	30%	40%
AT	**13.0**	0.0	0.0	2.1	4.1	6.1	7.9	11.4	17.6	27.8	36.0
		0.1	0.0	1.7	3.3	4.9	6.4	9.4	15.2	25.0	32.9
		0.2	0.0	1.3	2.5	3.7	4.9	7.2	12.6	21.8	29.4
		0.3	0.0	0.9	1.7	2.5	3.3	5.0	9.8	18.3	25.4
		0.4	0.0	0.4	0.9	1.3	1.7	2.6	6.9	14.4	20.9
		0.5	0.0	0.0	0.0	0.0	0.0	0.0	3.7	10.1	15.6
BE	**7.5**	0.0	0.0	2.3	4.4	6.5	9.9	16.9	23.1	33.3	41.5
		0.1	0.0	1.8	3.6	5.2	8.3	14.9	20.7	30.5	38.4
		0.2	0.0	1.4	2.7	4.0	6.7	12.7	18.1	27.3	34.9
		0.3	0.0	0.9	1.8	2.7	5.1	10.5	15.3	23.8	30.9
		0.4	0.0	0.5	0.9	1.4	3.4	8.1	12.4	19.9	26.4
		0.5	0.0	0.0	0.0	0.0	1.6	5.5	9.2	15.6	21.1
DK	**21.0**	0.0	0.0	1.9	3.8	5.5	7.2	10.3	13.2	19.8	28.0
		0.1	0.0	1.5	3.0	4.5	5.9	8.5	10.9	17.0	24.9
		0.2	0.0	1.2	2.3	3.4	4.5	6.5	8.5	13.8	21.4
		0.3	0.0	0.8	1.5	2.3	3.0	4.5	5.9	10.3	17.4
		0.4	0.0	0.4	0.8	1.2	1.5	2.3	3.0	6.4	12.9
		0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	7.6
FI	**0.0**	0.0	0.0	4.9	9.8	14.5	19.2	28.4	37.5	56.0	76.2
		0.1	0.0	4.5	8.9	13.3	17.7	26.5	35.3	53.9	74.7
		0.2	0.0	4.0	8.0	12.1	16.1	24.4	33.0	51.6	73.1
		0.3	0.0	3.5	7.1	10.8	14.5	22.3	30.6	49.0	71.3
		0.4	0.0	3.0	6.2	9.5	12.9	20.0	27.9	46.1	69.1
		0.5	0.0	2.6	5.3	8.1	11.1	17.6	25.0	42.9	66.7
FR	**0.0**	0.0	0.0	4.9	9.8	14.5	19.2	28.4	37.5	56.0	76.2
		0.1	0.0	4.5	8.9	13.3	17.7	26.5	35.3	53.9	74.7
		0.2	0.0	4.0	8.0	12.1	16.1	24.4	33.0	51.6	73.1
		0.3	0.0	3.5	7.1	10.8	14.5	22.3	30.6	49.0	71.3
		0.4	0.0	3.0	6.2	9.5	12.9	20.0	27.9	46.1	69.1
		0.5	0.0	2.6	5.3	8.1	11.1	17.6	25.0	42.9	66.7
DE	**21.0**	0.0	0.0	1.9	3.8	5.5	7.2	10.3	13.2	19.8	28.0
		0.1	0.0	1.5	3.0	4.5	5.9	8.5	10.9	17.0	24.9
		0.2	0.0	1.2	2.3	3.4	4.5	6.5	8.5	13.8	21.4
		0.3	0.0	0.8	1.5	2.3	3.0	4.5	5.9	10.3	17.4
		0.4	0.0	0.4	0.8	1.2	1.5	2.3	3.0	6.4	12.9
		0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	7.6
GR	**-25.0**	0.0	0.0	8.1	16.0	23.8	31.6	47.0	62.5	81.0	101.2
		0.1	0.0	7.5	14.9	22.4	29.8	44.9	60.3	78.9	99.7
		0.2	0.0	6.9	13.9	20.9	28.0	42.7	58.0	76.6	98.1
		0.3	0.0	6.3	12.8	19.4	26.2	40.4	55.6	74.0	96.3
		0.4	0.0	5.7	11.7	17.8	24.2	37.9	52.9	71.1	94.1
		0.5	0.0	5.1	10.5	16.2	22.2	35.3	50.0	67.9	91.7

Table 8: continued.

IE	**-13.0**	0.0	0.0	7.8	15.4	23.0	30.5	41.4	50.5	69.0	89.2
		0.1	0.0	7.2	14.5	21.7	28.9	39.5	48.3	66.9	87.7
		0.2	0.0	6.7	13.5	20.4	27.4	37.4	46.0	64.6	86.1
		0.3	0.0	6.2	12.5	19.0	25.7	35.3	43.6	62.0	84.3
		0.4	0.0	5.7	11.5	17.6	24.0	33.0	40.9	59.1	82.1
		0.5	0.0	5.1	10.5	16.2	22.2	30.6	38.0	55.9	79.7
IT	**6.5**	0.0	0.0	2.3	4.5	7.0	10.9	17.9	24.1	34.3	42.5
		0.1	0.0	1.8	3.6	5.7	9.3	15.9	21.7	31.5	39.4
		0.2	0.0	1.4	2.7	4.5	7.7	13.7	19.1	28.3	35.9
		0.3	0.0	0.9	1.8	3.2	6.1	11.5	16.3	24.8	31.9
		0.4	0.0	0.5	0.9	1.9	4.4	9.1	13.4	20.9	27.4
		0.5	0.0	0.0	0.0	0.5	2.6	6.5	10.2	16.6	22.1
LU	**28.0**	0.0	0.0	1.8	3.4	5.0	6.5	9.4	12.0	16.6	21.0
		0.1	0.0	1.4	2.8	4.1	5.3	7.7	9.9	13.9	17.9
		0.2	0.0	1.1	2.1	3.1	4.1	5.9	7.7	11.0	14.4
		0.3	0.0	0.7	1.4	2.1	2.8	4.1	5.3	7.7	10.4
		0.4	0.0	0.4	0.7	1.1	1.4	2.1	2.8	4.1	5.9
		0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6
NL	**6.0**	0.0	0.0	2.3	4.5	7.5	11.4	18.4	24.6	34.8	43.0
		0.1	0.0	1.8	3.6	6.2	9.8	16.4	22.2	32.0	39.9
		0.2	0.0	1.4	2.7	5.0	8.2	14.2	19.6	28.8	36.4
		0.3	0.0	0.9	1.8	3.7	6.6	12.0	16.8	25.3	32.4
		0.4	0.0	0.5	0.9	2.4	4.9	9.6	13.9	21.4	27.9
		0.5	0.0	0.0	0.0	1.0	3.1	7.0	10.7	17.1	22.6
PT	**-27.0**	0.0	0.0	8.1	16.1	23.9	31.7	47.3	62.8	83.0	103.2
		0.1	0.0	7.5	15.0	22.5	30.0	45.1	60.6	80.9	101.7
		0.2	0.0	6.9	13.9	21.0	28.2	42.9	58.3	78.6	100.1
		0.3	0.0	6.3	12.8	19.4	26.3	40.5	55.7	76.0	98.3
		0.4	0.0	5.7	11.7	17.9	24.3	38.0	53.0	73.1	96.1
		0.5	0.0	5.1	10.5	16.2	22.2	35.3	50.0	69.9	93.7
ES	**-15.0**	0.0	0.0	7.8	15.5	23.1	30.7	43.4	52.5	71.0	91.2
		0.1	0.0	7.3	14.5	21.8	29.1	41.5	50.3	68.9	89.7
		0.2	0.0	6.8	13.6	20.5	27.5	39.4	48.0	66.6	88.1
		0.3	0.0	6.2	12.6	19.1	25.8	37.3	45.6	64.0	86.3
		0.4	0.0	5.7	11.6	17.7	24.0	35.0	42.9	61.1	84.1
		0.5	0.0	5.1	10.5	16.2	22.2	32.6	40.0	57.9	81.7
SE	**-4.0**	0.0	0.0	7.5	13.8	18.5	23.2	32.4	41.5	60.0	80.2
		0.1	0.0	7.1	12.9	17.3	21.7	30.5	39.3	57.9	78.7
		0.2	0.0	6.6	12.0	16.1	20.1	28.4	37.0	55.6	77.1
		0.3	0.0	6.1	11.1	14.8	18.5	26.3	34.6	53.0	75.3
		0.4	0.0	5.6	10.2	13.5	16.9	24.0	31.9	50.1	73.1
		0.5	0.0	5.1	9.3	12.1	15.1	21.6	29.0	46.9	70.7
UK	**12.5**	0.0	0.0	2.1	4.2	6.1	8.0	11.9	18.1	28.3	36.5
		0.1	0.0	1.7	3.4	5.0	6.5	9.9	15.7	25.5	33.4
		0.2	0.0	1.3	2.5	3.8	5.0	7.7	13.1	22.3	29.9
		0.3	0.0	0.9	1.7	2.5	3.4	5.5	10.3	18.8	25.9
		0.4	0.0	0.4	0.9	1.3	1.7	3.1	7.4	14.9	21.4
		0.5	0.0	0.0	0.0	0.0	0.0	0.5	4.2	10.6	16.1
EU-15	**8.0**	**0.0**	**0.0**	**2.2**	**4.4**	**6.4**	**9.4**	**16.4**	**22.6**	**32.8**	**41.0**
		0.1	**0.0**	**1.8**	**3.5**	**5.2**	**7.8**	**14.4**	**20.2**	**30.0**	**37.9**
		0.2	**0.0**	**1.4**	**2.7**	**4.0**	**6.2**	**12.2**	**17.6**	**26.8**	**34.4**
		0.3	**0.0**	**0.9**	**1.8**	**2.7**	**4.6**	**10.0**	**14.8**	**23.3**	**30.4**
		0.4	**0.0**	**0.5**	**0.9**	**1.4**	**2.9**	**7.6**	**11.9**	**19.4**	**25.9**
		0.5	**0.0**	**0.0**	**0.0**	**0.0**	**1.1**	**5.0**	**8.7**	**15.1**	**20.6**

Table 9: The undershooting U listed in Table 8 multiplied with the factor $(-13/20)$ to reconcile the Und&VT concept with the emissions reporting for the EU and to establish the linear path undershooting targets for 2003.

MS	δ_{KP} **%**	α **1**	**Undershooting U in % for** $\rho =$								
			0%	**2.5%**	**5%**	**7.5%**	**10%**	**15%**	**20%**	**30%**	**40%**
AT	**-8.5**	0.0	0,0	-1,4	-2,7	-3,9	-5,1	-7,4	-11,4	-18,1	-23,4
		0.1	0,0	-1,1	-2,2	-3,2	-4,2	-6,1	-9,9	-16,2	-21,4
		0.2	0,0	-0,8	-1,6	-2,4	-3,2	-4,7	-8,2	-14,2	-19,1
		0.3	0,0	-0,6	-1,1	-1,6	-2,2	-3,2	-6,4	-11,9	-16,5
		0.4	0,0	-0,3	-0,6	-0,8	-1,1	-1,7	-4,5	-9,4	-13,6
		0.5	0,0	0,0	0,0	0,0	0,0	0,0	-2,4	-6,6	-10,1
BE	**-4.9**	0.0	0,0	-1,5	-2,9	-4,2	-6,4	-11,0	-15,0	-21,7	-27,0
		0.1	0,0	-1,2	-2,3	-3,4	-5,4	-9,7	-13,4	-19,8	-25,0
		0.2	0,0	-0,9	-1,8	-2,6	-4,4	-8,3	-11,8	-17,8	-22,7
		0.3	0,0	-0,6	-1,2	-1,8	-3,3	-6,8	-10,0	-15,5	-20,1
		0.4	0,0	-0,3	-0,6	-0,9	-2,2	-5,2	-8,0	-13,0	-17,1
		0.5	0,0	0,0	0,0	0,0	-1,0	-3,6	-6,0	-10,1	-13,7
DK	**-13.7**	0.0	0,0	-1,3	-2,4	-3,6	-4,7	-6,7	-8,6	-12,9	-18,2
		0.1	0,0	-1,0	-2,0	-2,9	-3,8	-5,5	-7,1	-11,0	-16,2
		0.2	0,0	-0,8	-1,5	-2,2	-2,9	-4,2	-5,5	-9,0	-13,9
		0.3	0,0	-0,5	-1,0	-1,5	-2,0	-2,9	-3,8	-6,7	-11,3
		0.4	0,0	-0,3	-0,5	-0,8	-1,0	-1,5	-2,0	-4,2	-8,4
		0.5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	-1,4	-4,9
FI	**0.0**	0.0	0,0	-3,2	-6,4	-9,4	-12,5	-18,5	-24,4	-36,4	-49,5
		0.1	0,0	-2,9	-5,8	-8,7	-11,5	-17,2	-23,0	-35,0	-48,6
		0.2	0,0	-2,6	-5,2	-7,8	-10,5	-15,9	-21,5	-33,5	-47,5
		0.3	0,0	-2,3	-4,6	-7,0	-9,4	-14,5	-19,9	-31,8	-46,3
		0.4	0,0	-2,0	-4,0	-6,2	-8,4	-13,0	-18,1	-30,0	-44,9
		0.5	0,0	-1,7	-3,4	-5,3	-7,2	-11,5	-16,3	-27,9	-43,3
FR	**0.0**	0.0	0,0	-3,2	-6,4	-9,4	-12,5	-18,5	-24,4	-36,4	-49,5
		0.1	0,0	-2,9	-5,8	-8,7	-11,5	-17,2	-23,0	-35,0	-48,6
		0.2	0,0	-2,6	-5,2	-7,8	-10,5	-15,9	-21,5	-33,5	-47,5
		0.3	0,0	-2,3	-4,6	-7,0	-9,4	-14,5	-19,9	-31,8	-46,3
		0.4	0,0	-2,0	-4,0	-6,2	-8,4	-13,0	-18,1	-30,0	-44,9
		0.5	0,0	-1,7	-3,4	-5,3	-7,2	-11,5	-16,3	-27,9	-43,3
DE	**-13.7**	0.0	0,0	-1,3	-2,4	-3,6	-4,7	-6,7	-8,6	-12,9	-18,2
		0.1	0,0	-1,0	-2,0	-2,9	-3,8	-5,5	-7,1	-11,0	-16,2
		0.2	0,0	-0,8	-1,5	-2,2	-2,9	-4,2	-5,5	-9,0	-13,9
		0.3	0,0	-0,5	-1,0	-1,5	-2,0	-2,9	-3,8	-6,7	-11,3
		0.4	0,0	-0,3	-0,5	-0,8	-1,0	-1,5	-2,0	-4,2	-8,4
		0.5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	-1,4	-4,9
GR	**16.3**	0.0	0,0	-5,2	-10,4	-15,5	-20,5	-30,5	-40,6	-52,7	-65,8
		0.1	0,0	-4,9	-9,7	-14,5	-19,4	-29,2	-39,2	-51,3	-64,8
		0.2	0,0	-4,5	-9,0	-13,6	-18,2	-27,8	-37,7	-49,8	-63,8
		0.3	0,0	-4,1	-8,3	-12,6	-17,0	-26,2	-36,1	-48,1	-62,6
		0.4	0,0	-3,7	-7,6	-11,6	-15,8	-24,6	-34,4	-46,2	-61,2
		0.5	0,0	-3,3	-6,8	-10,5	-14,4	-22,9	-32,5	-44,1	-59,6

Table 9: continued.

IE	**8.5**	0.0	0,0	-1,4	-2,7	-3,9	-5,1	-7,4	-11,4	-18,1	-23,4
		0.1	0,0	-1,1	-2,2	-3,2	-4,2	-6,1	-9,9	-16,2	-21,4
		0.2	0,0	-0,8	-1,6	-2,4	-3,2	-4,7	-8,2	-14,2	-19,1
		0.3	0,0	-0,6	-1,1	-1,6	-2,2	-3,2	-6,4	-11,9	-16,5
		0.4	0,0	-0,3	-0,6	-0,8	-1,1	-1,7	-4,5	-9,4	-13,6
		0.5	0,0	0,0	0,0	0,0	0,0	0,0	-2,4	-6,6	-10,1
IT	**-4.2**	0.0	0,0	-1,5	-2,9	-4,2	-6,4	-11,0	-15,0	-21,7	-27,0
		0.1	0,0	-1,2	-2,3	-3,4	-5,4	-9,7	-13,4	-19,8	-25,0
		0.2	0,0	-0,9	-1,8	-2,6	-4,4	-8,3	-11,8	-17,8	-22,7
		0.3	0,0	-0,6	-1,2	-1,8	-3,3	-6,8	-10,0	-15,5	-20,1
		0.4	0,0	-0,3	-0,6	-0,9	-2,2	-5,2	-8,0	-13,0	-17,1
		0.5	0,0	0,0	0,0	0,0	-1,0	-3,6	-6,0	-10,1	-13,7
LU	**-18.2**	0.0	0,0	-1,3	-2,4	-3,6	-4,7	-6,7	-8,6	-12,9	-18,2
		0.1	0,0	-1,0	-2,0	-2,9	-3,8	-5,5	-7,1	-11,0	-16,2
		0.2	0,0	-0,8	-1,5	-2,2	-2,9	-4,2	-5,5	-9,0	-13,9
		0.3	0,0	-0,5	-1,0	-1,5	-2,0	-2,9	-3,8	-6,7	-11,3
		0.4	0,0	-0,3	-0,5	-0,8	-1,0	-1,5	-2,0	-4,2	-8,4
		0.5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	-1,4	-4,9
NL	**-3.9**	0.0	0,0	-3,2	-6,4	-9,4	-12,5	-18,5	-24,4	-36,4	-49,5
		0.1	0,0	-2,9	-5,8	-8,7	-11,5	-17,2	-23,0	-35,0	-48,6
		0.2	0,0	-2,6	-5,2	-7,8	-10,5	-15,9	-21,5	-33,5	-47,5
		0.3	0,0	-2,3	-4,6	-7,0	-9,4	-14,5	-19,9	-31,8	-46,3
		0.4	0,0	-2,0	-4,0	-6,2	-8,4	-13,0	-18,1	-30,0	-44,9
		0.5	0,0	-1,7	-3,4	-5,3	-7,2	-11,5	-16,3	-27,9	-43,3
PT	**17.6**	0.0	0,0	-3,2	-6,4	-9,4	-12,5	-18,5	-24,4	-36,4	-49,5
		0.1	0,0	-2,9	-5,8	-8,7	-11,5	-17,2	-23,0	-35,0	-48,6
		0.2	0,0	-2,6	-5,2	-7,8	-10,5	-15,9	-21,5	-33,5	-47,5
		0.3	0,0	-2,3	-4,6	-7,0	-9,4	-14,5	-19,9	-31,8	-46,3
		0.4	0,0	-2,0	-4,0	-6,2	-8,4	-13,0	-18,1	-30,0	-44,9
		0.5	0,0	-1,7	-3,4	-5,3	-7,2	-11,5	-16,3	-27,9	-43,3
ES	**9.8**	0.0	0,0	-1,3	-2,4	-3,6	-4,7	-6,7	-8,6	-12,9	-18,2
		0.1	0,0	-1,0	-2,0	-2,9	-3,8	-5,5	-7,1	-11,0	-16,2
		0.2	0,0	-0,8	-1,5	-2,2	-2,9	-4,2	-5,5	-9,0	-13,9
		0.3	0,0	-0,5	-1,0	-1,5	-2,0	-2,9	-3,8	-6,7	-11,3
		0.4	0,0	-0,3	-0,5	-0,8	-1,0	-1,5	-2,0	-4,2	-8,4
		0.5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	-1,4	-4,9
SE	**2.6**	0.0	0,0	-5,2	-10,4	-15,5	-20,5	-30,5	-40,6	-52,7	-65,8
		0.1	0,0	-4,9	-9,7	-14,5	-19,4	-29,2	-39,2	-51,3	-64,8
		0.2	0,0	-4,5	-9,0	-13,6	-18,2	-27,8	-37,7	-49,8	-63,8
		0.3	0,0	-4,1	-8,3	-12,6	-17,0	-26,2	-36,1	-48,1	-62,6
		0.4	0,0	-3,7	-7,6	-11,6	-15,8	-24,6	-34,4	-46,2	-61,2
		0.5	0,0	-3,3	-6,8	-10,5	-14,4	-22,9	-32,5	-44,1	-59,6
UK	**-8.1**	0.0	0,0	-5,0	-10,0	-14,9	-19,8	-26,9	-32,8	-44,9	-58,0
		0.1	0,0	-4,7	-9,4	-14,1	-18,8	-25,7	-31,4	-43,5	-57,0
		0.2	0,0	-4,4	-8,8	-13,2	-17,8	-24,3	-29,9	-42,0	-56,0
		0.3	0,0	-4,0	-8,1	-12,4	-16,7	-23,0	-28,3	-40,3	-54,8
		0.4	0,0	-3,7	-7,5	-11,5	-15,6	-21,5	-26,6	-38,4	-53,4
		0.5	0,0	-3,3	-6,8	-10,5	-14,4	-19,9	-24,7	-36,3	-51,8
EU-15	**-5.2**	**0.0**	**0.0**	**-1.5**	**-2.8**	**-4.2**	**-6.1**	**-10.7**	**-14.7**	**-21.3**	**-26.6**
		0.1	**0.0**	**-1.2**	**-2.3**	**-3.4**	**-5.1**	**-9.3**	**-13.1**	**-19.5**	**-24.6**
		0.2	**0.0**	**-0.9**	**-1.7**	**-2.6**	**-4.1**	**-7.9**	**-11.4**	**-17.4**	**-22.4**
		0.3	**0.0**	**-0.6**	**-1.2**	**-1.7**	**-3.0**	**-6.5**	**-9.6**	**-15.2**	**-19.8**
		0.4	**0.0**	**-0.3**	**-0.6**	**-0.9**	**-1.9**	**-4.9**	**-7.7**	**-12.6**	**-16.8**
		0.5	**0.0**	**0.0**	**0.0**	**0.0**	**-0.7**	**-3.3**	**-5.6**	**-9.8**	**-13.4**

4 Interpretation of Results and Conclusions

To interpret the results for 2003, the following are displayed:

(I) U by ρ with α as a parameter;
i.e., the Member States' undershooting U that matches the relative uncertainty ρ in the intervals $[0,5[$, $[5,10[$, $[10,20[$ and $[20,40[$ %, while the risk α takes on the values 0, 0.1, …, 0.5.

(II) U by α with ρ as a parameter;
i.e., the Member States' undershooting U that matches the risk $\alpha = 0.5$ and α in the intervals $[0.4, 0.5[$, $[0.3, 0.4[$, $[0.2, 0.3[$, $[0.1, 0.2[$ and $[0, 0.1[$, while the relative uncertainty ρ takes on the values 5, 10, 20 and 40%.

With respect to ρ, Jonas and Nilsson (2001: Section 4.1.3) is followed, who recommend the application of relative uncertainty classes as a common good practice measure. The classes constitute a robust means to get an effective grip on uncertainties in light of the numerous data limitations and intra and inter-country inconsistencies, which do not justify the reporting of exact relative uncertainties. The procedure with respect to α is similar.

The DTIs displayed in Figure 2 are always shown to contrast the Member States' linear path undershooting targets for the year 2003 with their actual emission situation in that year.

(I) U by ρ with α as a parameter. Figure 5 displays U by ρ for $\alpha = 0.5$. For this α value, U equals zero (Case 1: equations (6)) or $U_{Gap} > 0$ (Cases 2–4: equations (9), (13) and (17) in which U_{Gap} is > 0 because it has not yet been multiplied with the factor $(-13/20)$). U_{Gap} is the initial or obligatory undershooting that is required to achieve detectability before the Member States are permitted to make economic use of any excess emission reductions.

U_{Gap} is a function of δ_{crit} (Equations (10), (14) and (18)) and thus of ρ (equation (1)). This explains the different initial or obligatory undershooting that Member States have to fulfill in dependence of the relative uncertainty with which they report their emissions. Of interest here are the four countries that exhibit a negative DTI: DE, FR, SE and the UK (Figure 2). Given $\alpha = 0.5$, DE is the best potential seller followed by the UK, SE and FR (Figure 5). DE can report with a relative uncertainty of up to 40% (rounded) and still exhibit a detectable emission signal, while the UK must report with a relative uncertainty falling into the interval $[20,40[$ (more exactly: up to 26%), and both SE and FR even with a relative uncertainty falling into the interval $[0,5[$ % (more exactly: up to 3.6% and 2.8% respectively).[9]

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[9] The exact values are derived by demanding that U_{Gap} (as given by equation (10) for DE and the UK and equation (14) for FR and SE) equals a Member State's DTI (multiplied with $(-20/13)$) and resolving the resulting equation for the relative uncertainty ρ.

Figures 6–10 display U by ρ for $\alpha = 0.4,...,0.0$. These figures can be interpreted similarly to Figure 5, bearing in mind that U increases in absolute terms with decreasing α. For $\alpha = 0.0$ (Figure 10), both DE and the UK must report with a relative uncertainty falling into the interval $[10,20[$ (more exactly: up to 10%), and both SE and FR even with a relative uncertainty falling into the interval $[0,5[\%$ (more exactly: up to 2.6% and 1.5%, respectively).[10]

(II) U by a with ρ as a parameter. Figure 11 displays U by α for $\rho = 5\%$. For this ρ value, a white bar or, equivalently, a $U_{Gap} < 0$ (i.e., > 0 if the factor $(-13/20)$ is disregarded) appears only for Member States committed to emission limitation (ES, FI, FR, GR, IE, PT and SE; see Table 1). A $U_{Gap} < 0$ satisfies the demand for detectable signals. As it becomes obvious, the white bars represent the major part of U. Their length is equivalent to the length of the green bars in Figure 5.

With increasing ρ (Figures 12–14), an increasing number of Member States committed to emission reduction also exhibit a $U_{Gap} < 0$, for $\rho = 40\%$ eventually all of them (Figure 14). For $\rho = 10\%$, the length of the white bars is equivalent to the combined length of the green and yellow bars in Figure 5; and so on until Figure 14 ($\rho = 40\%$), where the length of the white bars is equivalent to the combined length of the green, yellow, orange and red bars in Figure 5. In general, Figures 12–14 resolve U_{Gap} better than the remainder of U.

Here, interpretation I (U by ρ with α as a parameter; Figures 5–10) is preferred over interpretation II (U by α with ρ as a parameter; Figures 11–14), as the use of α instead of ρ as a parameter appears to be more readily acceptable. Nevertheless, Figures 11–14 are well suited to quickly survey U_{Gap} and analyze which Member State with a negative DTI meets U_{Gap} for a given ρ. (The UK, e.g., meets U_{Gap} for $\rho = 20\%$ but not any more for $\rho = 40\%$; Figures 13 and 14.)

The following four conclusions emerge from this study:

(1) Jonas *et al.* (2004a) motivated the application of preparatory signal detection in the context of the Kyoto Protocol as a necessary measure that should have been taken prior to/in negotiating the Protocol. To these ends, the authors have applied four preparatory signal detection techniques to the Annex I countries under the Kyoto Protocol. The frame of reference for preparatory signal detection is that Annex I countries comply with their committed emission targets in 2008–2012. By contrast, in this study one of these techniques, the Und&VT concept, is applied to the old Member States of the European Union under the EU burden sharing in compliance with the Kyoto Protocol, but with reference to the linear path (base year–commitment year) undershooting targets in 2003. The exercise shows that

[10] The exact values are derived by demanding that a Member State's DTI (multiplied with $(-20/13)$) is reproduced by using equation (6) for DE and the UK, (13) for FR and (17) for SE, respectively.

preparatory signal detection can also be applied in connection with intermediate emission targets.

(2) To advance the reporting of the EU, uncertainty and its consequences are taken into consideration in addition to the DTI, i.e., (i) the risk that a Member State's true emissions in the commitment year/period are above its true EU reference line; and (ii) the detectability of its target. It is anticipated that the evaluation of emission signals in terms of risk and detectability will become standard practice and that these two qualifiers will be accounted for in pricing GHG emission permits.

(3) In 2003 only four EU-15 Member States exhibit a negative DTI and thus appear as potential sellers: DE, FR, SE and the UK (Figure 2). However, expecting that the EU Member States exhibit relative uncertainties in the range of 5–10% and above rather than below excluding LUCF and Kyoto mechanisms (confer Table 2), the Member States require considerable undershooting of their EU-compatible, but detectable, targets if one wants to keep the risk low ($\alpha \approx 0.1$) that the Member States' true emissions in the commitment year/period are above their true EU reference lines. These conditions can only be met (equally well) by two Member States in the 10–20% relative uncertainty class, DE and the UK (Figure 9), while FR and SE can only act as potential high-risk sellers ($\alpha = 0.5$) within the 0–5% relative uncertainty class (Figure 5). The other EU-15 Member States exhibit positive DTIs, i.e., they do not meet their linear path (base year–commitment year) undershooting targets in 2003.

(4) The Und&VT concept requires detectable signals. Measuring emission reductions negatively and emission increases positively (i.e., in line with the reporting for the EU), it can be stated that the greater the committed emission limitation or reduction targets δ_{KP} and the greater the relative uncertainty ρ, with which Member States report their emissions, the smaller the initial or obligatory undershooting U_{Gap} is to achieve detectability. That is, for $\rho = 5\%$ only the EU-15 Member States committed to emission limitation (ES, FI, FR, GR, IE, PT and SE) require a $U_{Gap} < 0$. For these Member States, U_{Gap} represents the major part of the undershooting U (Figure 11). For $\rho = 10\%$, BE, IT, the NL as well as the EU-15 as a whole also require a $U_{Gap} < 0$ (Figure 12), indicating that somewhere within the 5–10% relative uncertainty range non-detectability will become a problem also for these Member States as well as the EU. The maximal (critical) relative uncertainties, with which they can report their emissions without compromising detectability, can be determined (Jonas *et al.*, 2004a: Section 3.1); these are, in absolute terms and with reference to 2010, 8.1% (BE), 7.0% (IT), 6.4% (NL) and 8.7% (EU-15), respectively, assuming that the emission limitation or reduction targets are met under the EU burden sharing in compliance with the Kyoto Protocol. From these numbers it becomes clear that the negotiations for the Kyoto Protocol were imprudent because they did not consider the consequences of uncertainty.

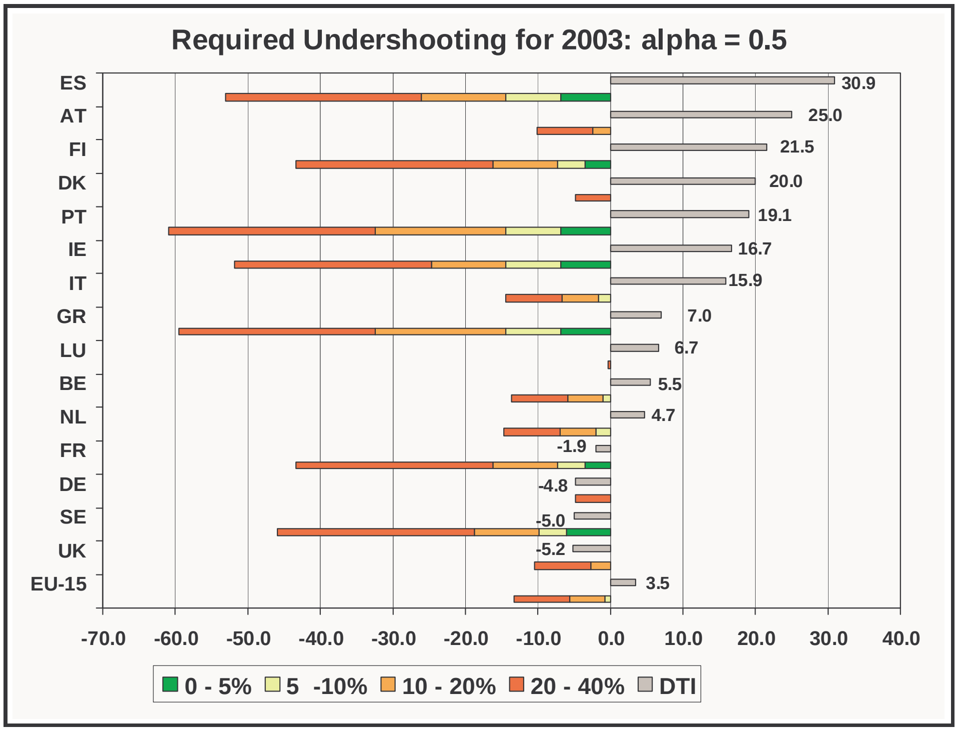

Figure 5: U by ρ (see intervals) for $\alpha = 0.5$ in addition to the DTI.

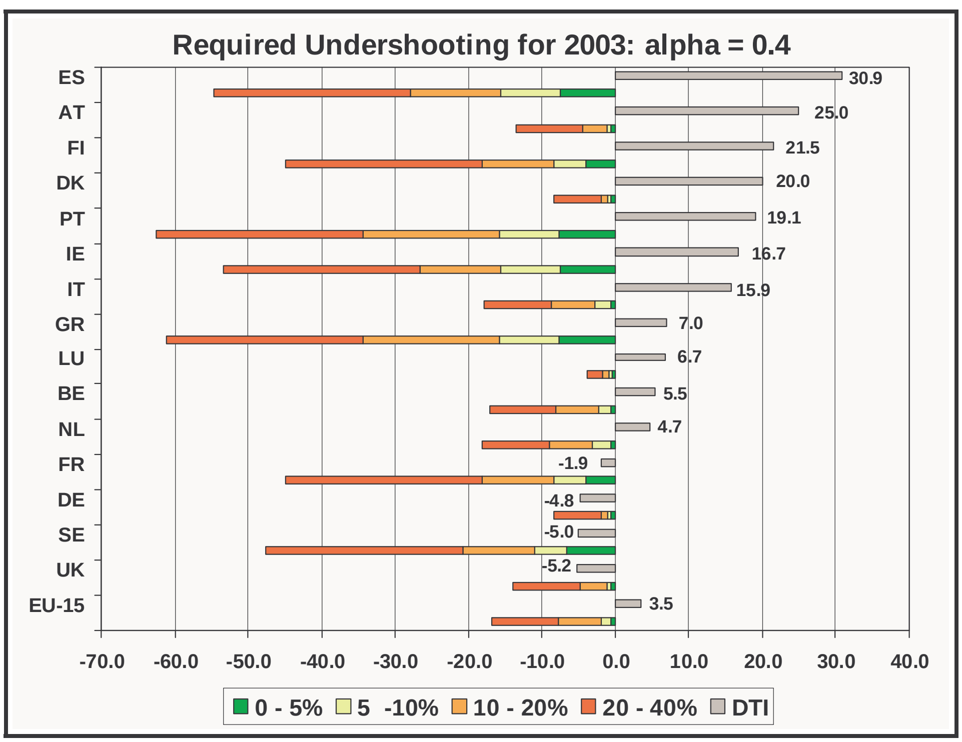

Figure 6: U by ρ (see intervals) for $\alpha = 0.4$ in addition to the DTI.

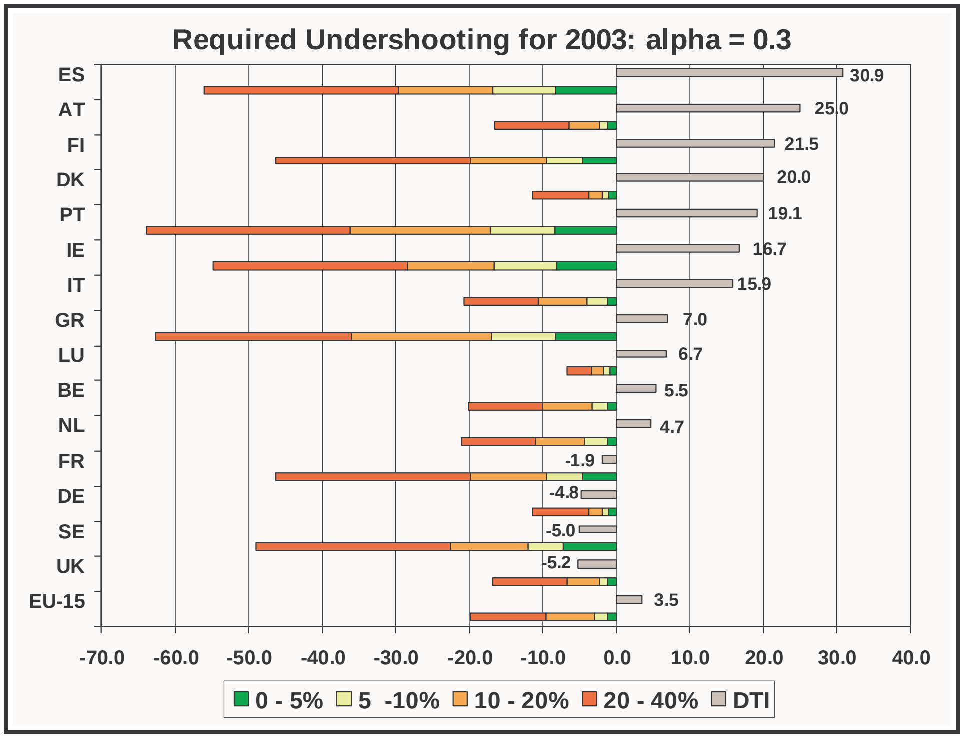

Figure 7: U by ρ (see intervals) for $\alpha = 0.3$ in addition to the DTI.

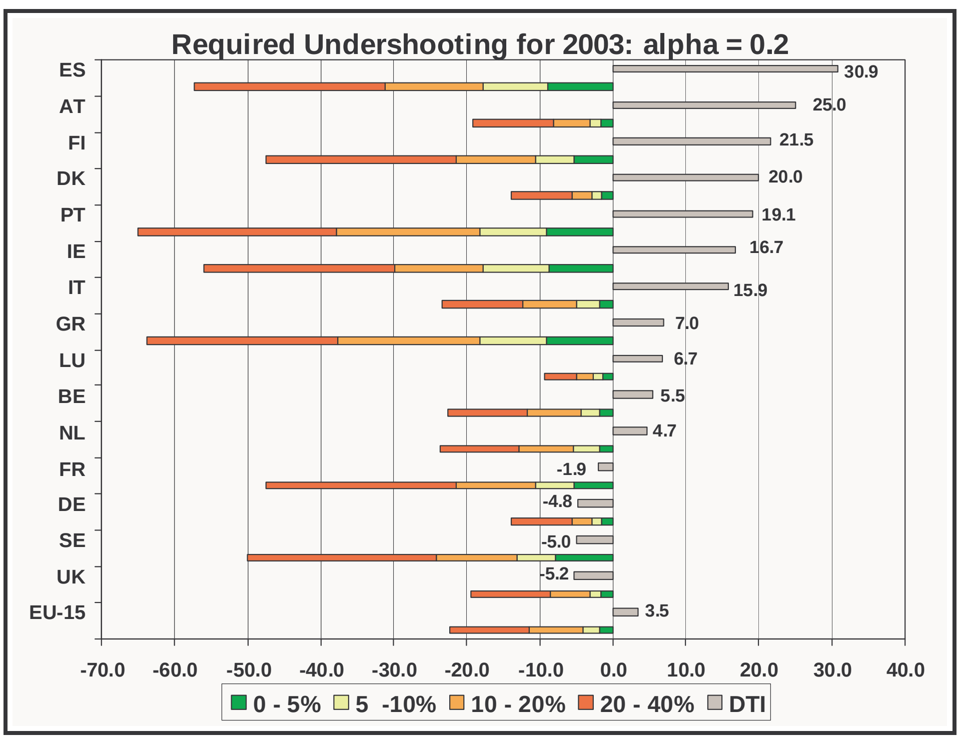

Figure 8: U by ρ (see intervals) for $\alpha = 0.2$ in addition to the DTI.

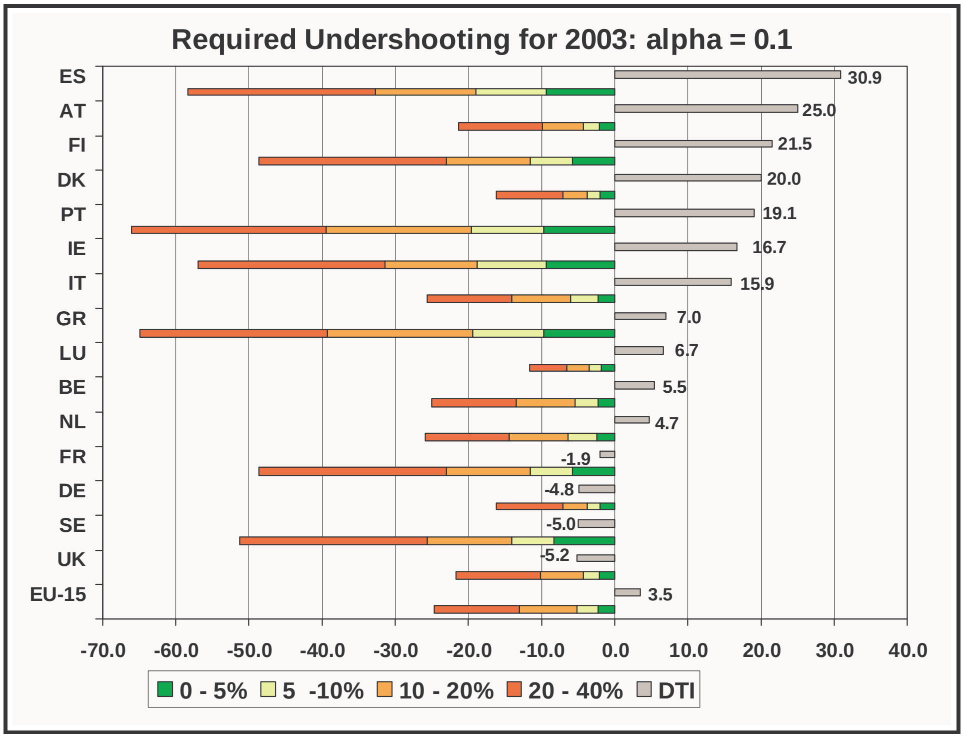

Figure 9: U by ρ (see intervals) for $\alpha = 0.1$ in addition to the DTI.

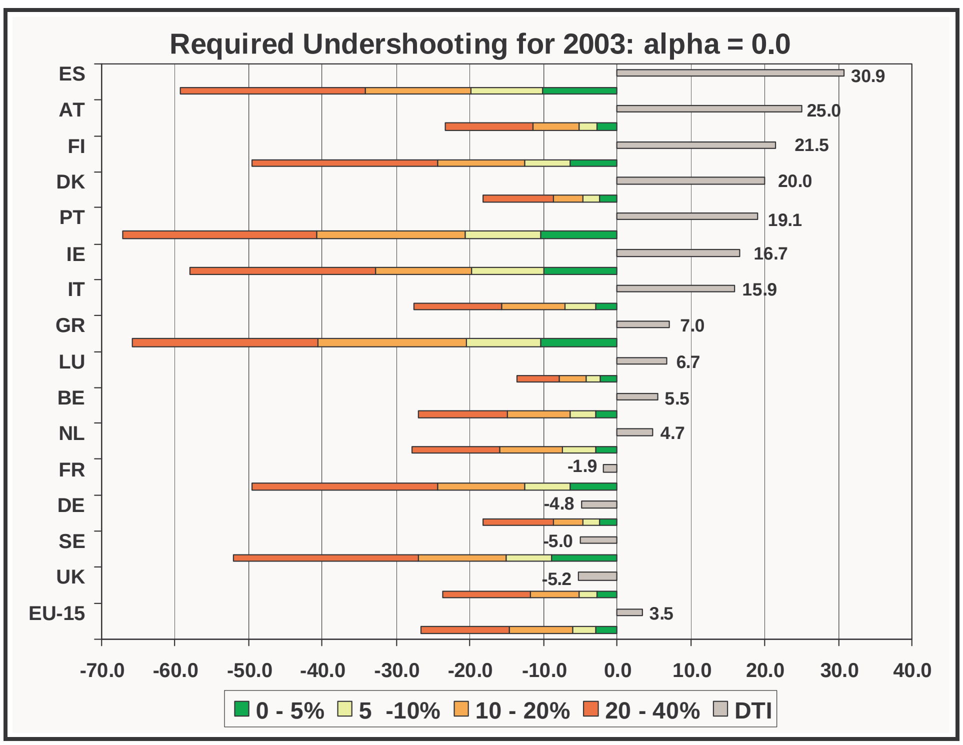

Figure 10: U by ρ (see intervals) for $\alpha = 0.0$ in addition to the DTI.

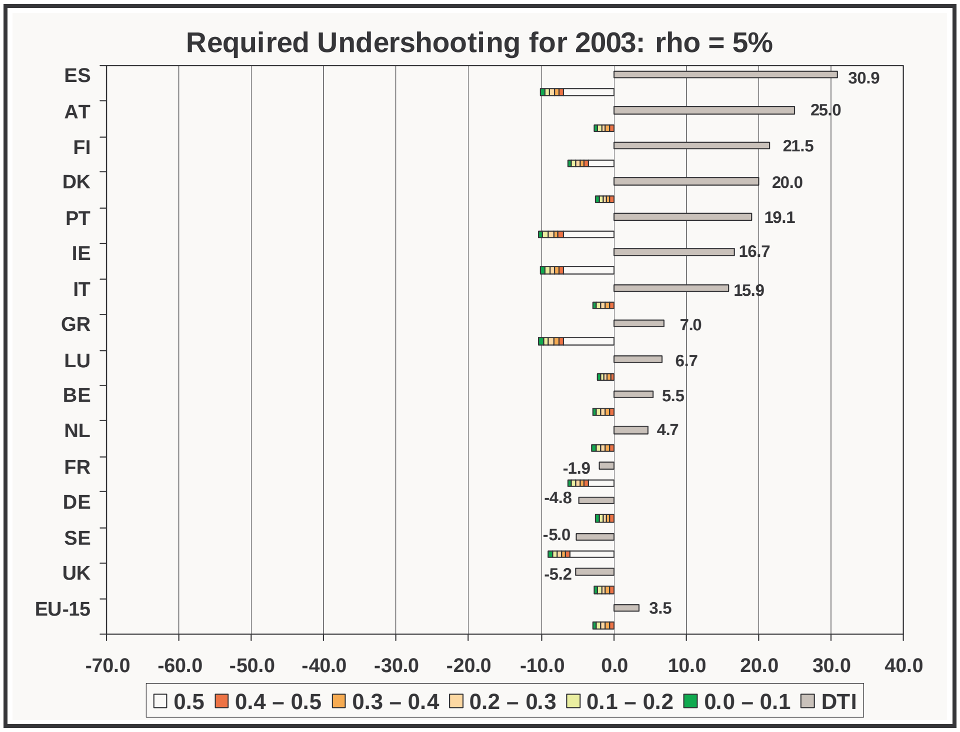

Figure 11: U by α (see value and intervals) for $\rho = 5\%$ in addition to the DTI.

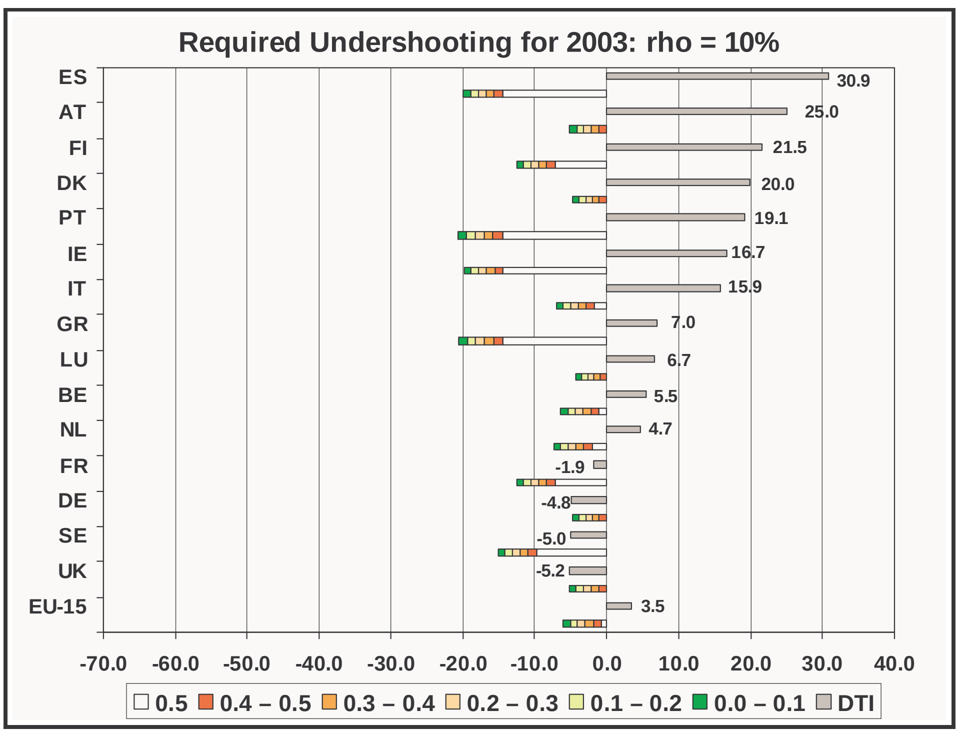

Figure 12: U by α (see value and intervals) for $\rho = 10\%$ in addition to the DTI.

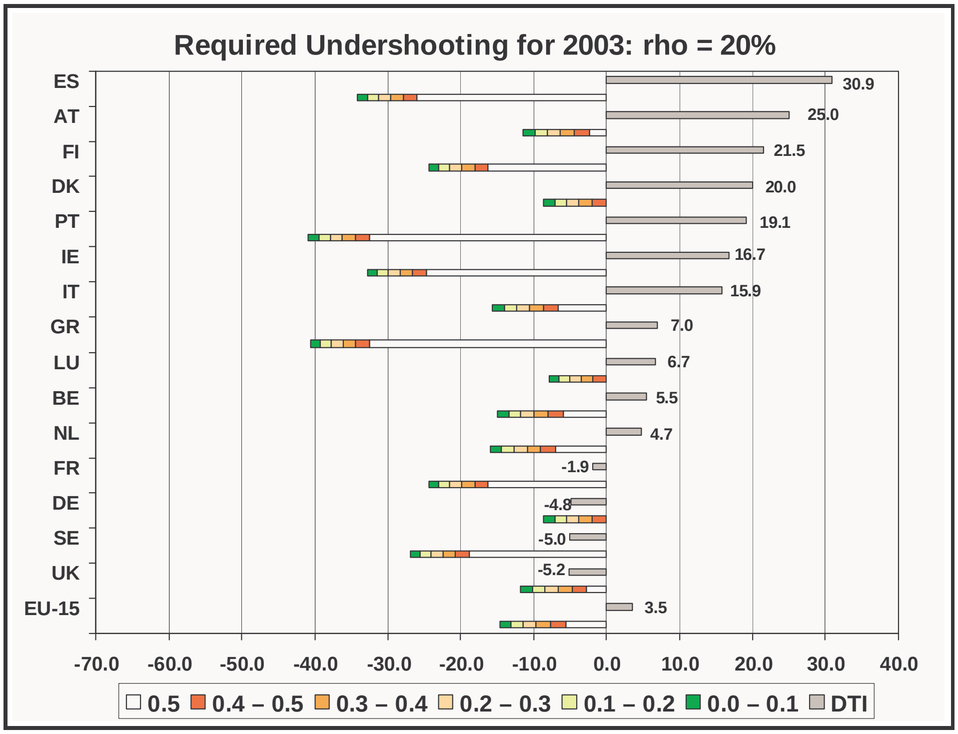

Figure 13: U by α (see value and intervals) for $\rho = 20\%$ in addition to the DTI.

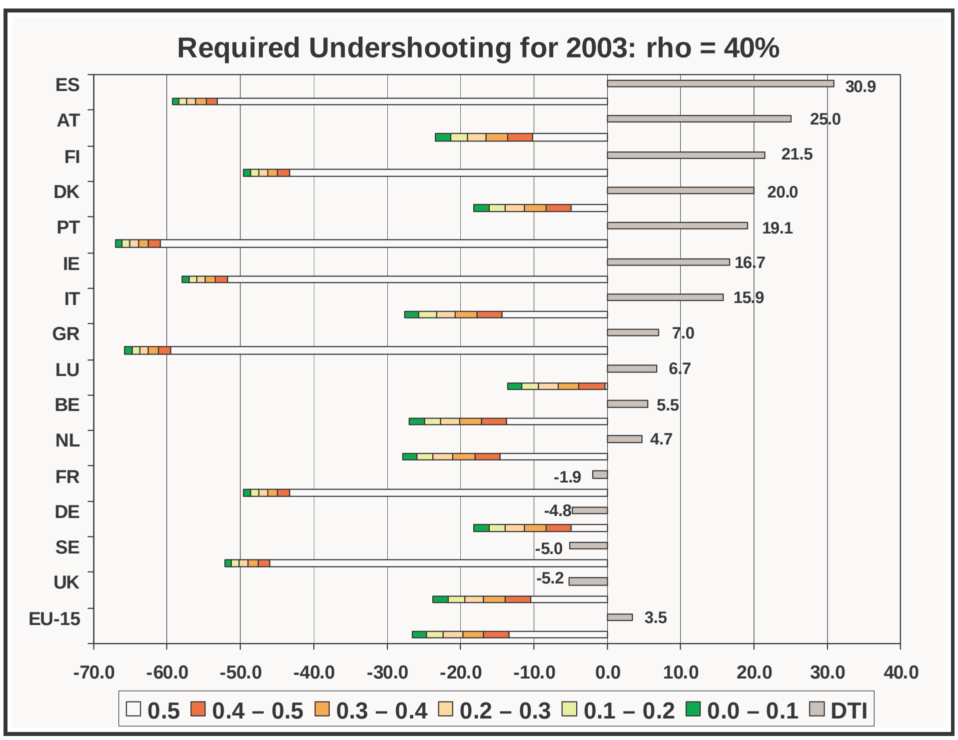

Figure 14: U by α (see value and intervals) for $\rho = 40\%$ in addition to the DTI.

References

Bun, A. (2006). Preparatory Signal Detection for the EU-25 Member States Under EU Burden Sharing—Advanced Monitoring Including Uncertainty (1990–2003). Interim Report IR-06-054, International Institute for Applied Systems Analysis, Laxenburg, Austria, pp. 39. Available at: http://www.iiasa.ac.at/Publications/Documents/IR-06-054.pdf.

EEA (2005a). Annual European Community Greenhouse Gas Inventory 1990–2003 and Inventory Report 2005. Technical Report No. 4, European Environment Agency (EEA), Copenhagen, Denmark. Available at: http://reports.eea.europa.eu/technical_report_2005_4/en/.

EEA (2005b). Greenhouse Gas Emission Trends and Projections in Europe 2005. Report No. 8, European Environment Agency (EEA), Copenhagen, Denmark. Available at: http://reports.eea.europa.eu/eea_report_2005_8/en.

IPCC (1997a,b,c). *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 1: Greenhouse Gas Inventory Reporting Instructions; Volume 2: Greenhouse Gas Inventory Workbook; Volume 3: Greenhouse Gas Inventory Reference Manual.* Intergovernmental Panel on Climate Change (IPCC) Working Group I (WG I) Technical Support Unit, IPCC/OECD/IEA, Bracknell, United Kingdom. Available at:http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm.

Jonas, M., S. Nilsson, M. Obersteiner, M. Gluck and Y. Ermoliev (1999). Verification Times Underlying the Kyoto Protocol: Global Benchmark Calculations. Interim Report IR-99-062, International Institute for Applied Systems Analysis, Laxenburg, Austria, pp. 43. Available at: http://www.iiasa.ac.at/Publications/Documents/IR-99-062.pdf.

Jonas, M. and S. Nilsson (2001). The Austrian Carbon Database (ACDb) Study—Overview. Interim Report IR-01-064, International Institute for Applied Systems Analysis, Laxenburg, Austria, pp. 131. Available at: http://www.iiasa.ac.at/Research/FOR/acdb.html.

Jonas, M., S. Nilsson, R. Bun, V. Dachuk, M. Gusti, J. Horabik, W. Jęda and Z. Nahorski (2004a). Preparatory Signal Detection for Annex I Countries under the Kyoto Protocol—A Lesson for the Post-Kyoto Policy Process. Interim Report IR-04-024, International Institute for Applied Systems Analysis, Laxenburg, Austria, pp. 91. Available at: http://www.iiasa.ac.at/Publications/Documents/IR-04-024.pdf.

Jonas, M., S. Nilsson, R. Bun, V. Dachuk, M. Gusti, J. Horabik, W. Jęda and Z. Nahorski (2004b). Preparatory Signal Detection for the EU Member States Under EU Burden Sharing—Advanced Monitoring Including Uncertainty (1990–2001). Interim Report IR-04-029, International Institute for Applied Systems Analysis, Laxenburg, Austria, pp. 29. Available at: http://www.iiasa.ac.at/Publications/Documents/IR-04-029.pdf.

Jonas, M., S. Nilsson, R. Bun, V. Dachuk, M. Gusti, J. Horabik, W. Jęda and Z. Nahorski (2004c). Preparatory Signal Detection for the EU Member States Under EU Burden Sharing—Advanced Monitoring Including Uncertainty (1990–2002). Interim Report IR-04-046, International Institute for Applied Systems Analysis, Laxenburg, Austria, pp. 29. Available at: http://www.iiasa.ac.at/Publicatins/Documents/IR-04-046.pdf.

Penman, J., D. Kruger, I. Galbally, T. Hiraishi, B. Nyenzi, S. Emmanuel, L. Buendia, R. Hoppaus, T. Martinsen, J. Meijer, K. Miwa and K. Tanabe (eds.) (2000). *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories.* Institute for Global Environmental Strategies, Hayama, Kanagawa, Japan. Available at: http://www.ipcc-nggip.iges.or.jp/public/gp/english/.

Ritter, M. (2006). Personal communication. Federal Environment Agency (Umweltbundesamt), Vienna, Austria, 25 April.

Acronyms and Nomenclature

EU	European Union
DTI	Distance-to-Target Indicator
GHG	Greenhouse Gas
KP	Kyoto Protocol
LUCF	Land-use Change and Forestry
MS	Member State
Und	Undershooting
Und&VT	Undershooting and Verification Time
VT	Verification Time

crit	critical
mod	modified
t	true

ISO Country Code

AT	Austria
BE	Belgium
DE	Germany
DK	Denmark
ES	Spain
FI	Finland
FR	France
GR	Greece
IE	Ireland
IT	Italy
LU	Luxembourg
NL	Netherlands
PT	Portugal
SE	Sweden
UK	United Kingdom