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Interim Report **IR-04-029**

Preparatory Signal Detection for the EU Member States Under EU Burden Sharing — Advanced Monitoring Including Uncertainty (1990–2001)

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Contents

Abstract

This study follows up the authors' collaborative IIASA Interim Report IR-04-024 (Jonas *et al.*, 2004), 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 excluded the 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 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.

In our study we apply one of these techniques, the combined undershooting and verification time (Und&VT) concept to advance the monitoring of the GHG emissions reported by the Member States of the European Union (EU). In contrast to the earlier study, we focus on the Member States' committed emission targets under the EU burden sharing in compliance with the Kyoto Protocol. We apply the Und&VT concept 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 the base year and the commitment year (here for 2001).

To advance the reporting of the EU we take 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; and (ii) the detectability of its target. Undershooting the committed EU target or EU-compatible, but detectable, target can decrease this risk. We contrast the Member States' linear path undershooting targets for the year 2001 with their actual emission situation in that year, for which we use the distance-to-target indicator (DTI) introduced by the European Environment Agency.

In 2001 only four countries exhibit a negative DTI and thus appear as potential sellers: Germany, Luxembourg, 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 emissions/removals due to LUCF, the Member States require

considerable undershooting of their EU-compatible, but detectable, targets if one wants to keep the associated risk low ($\alpha \approx 0.1$). These conditions can only be met by the three Member States Germany, Luxembourg and the United Kingdom — or Luxembourg, Germany and the United Kingdom if ranked in terms of creditability. Within the 5–10% relative uncertainty class, Sweden can only act as a potential high-risk seller. In contrast, with relative uncertainty increasing from 5 to 10%, the emission signal of the EU as a whole switches from “detectable” to “non-detectable”, indicating that the negotiations for the Kyoto Protocol were imprudent because they did not take uncertainty and its consequences into account.

We anticipate 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.

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Preparatory Signal Detection for the EU Member States Under EU Burden Sharing — Advanced Monitoring Including Uncertainty (1990–2001)

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1 Background and Objective

This study follows up the authors' collaborative IIASA Interim Report IR-04-024 (Jonas *et al.*, 2004). It applies the strictest of the preparatory signal detection techniques developed in this report, the combined undershooting and verification time (Und&VT) concept, to advance the monitoring of the greenhouse gas (GHG) emissions reported by the Member States of the European Union (EU) under EU burden sharing in compliance with the Kyoto Protocol. Under current monitoring, the Member States' emissions are evaluated in relation to the EU's actual (here: 2001) target and in terms of their positive and negative contributions to this target. This monitoring process is illustrated in Figures 1 and 2 and Table 1. They give details, for each Member State and the EU as a whole, of trends in emissions of GHGs (CO_2, CH_4, N_2O, HFCs, PFCs, SF6) up to 2001.[1] 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 2001 from the linear target path between 1990 and the EU target for 2008–2012, assuming that only domestic measures will be used. A negative DTI means that a Member State is below its linear target path, a positive DTI that a Member State is above its linear target path (EEA, 2003; Gugele *et al.*, 2003)[2]. As Figures 1 and 2 only present relative information of the kind "can sell versus must buy", we add Figure 3, which translates this information into absolute numbers based on the Member States' emissions in 2001 (Table 1) and their DTIs for that year. Figure 3 helps us to understand the 2001 situation of the EU in quantitative terms.

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[1] Emissions from international aviation and shipping, and emissions/removals due to land-use change and forestry (LUCF), are not covered (EEA, 2003).

[2] For example, Ireland is allowed a 13% increase from 1990 levels by 2008–2012, so its theoretical "linear target" for 2001 is a rise of no more than 7.2%. Its actual emissions in 2001 show an increase of 31.1% since 1990; hence, its "distance-to-target" is 31.1 − 7.2, or 23.9 index points. Germany's Kyoto target is a 21% reduction, so its theoretical "linear target" for 2001 is a decrease of 11.5%. Actual emissions in 2001 were 18.3% lower than in 1990; hence, its "distance-to-target" is (–18.3) – (–11.5), or –6.8 index points (EEA, 2003).

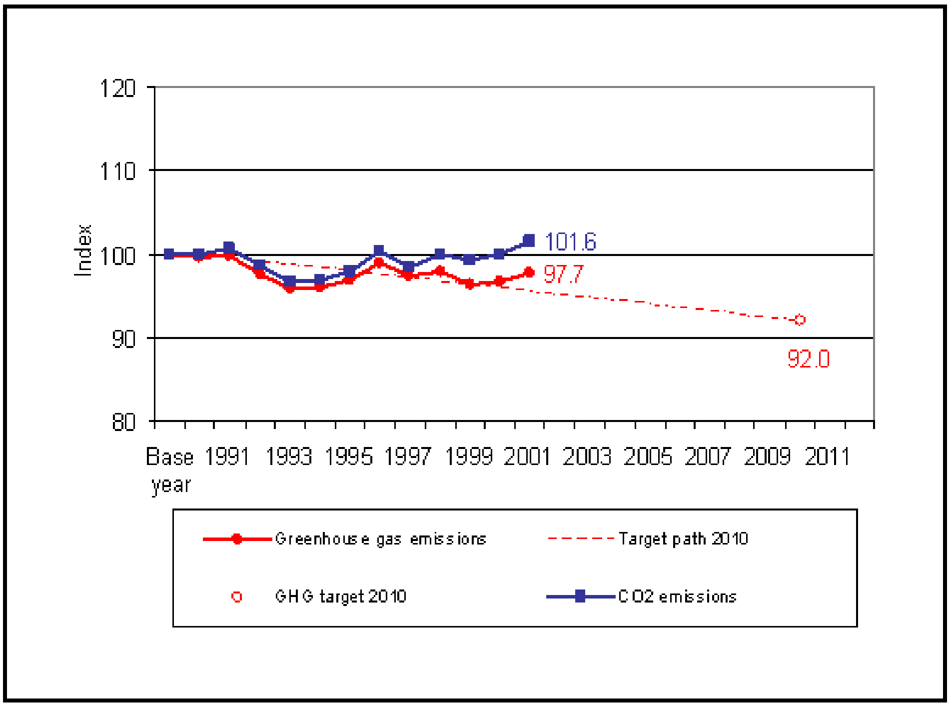
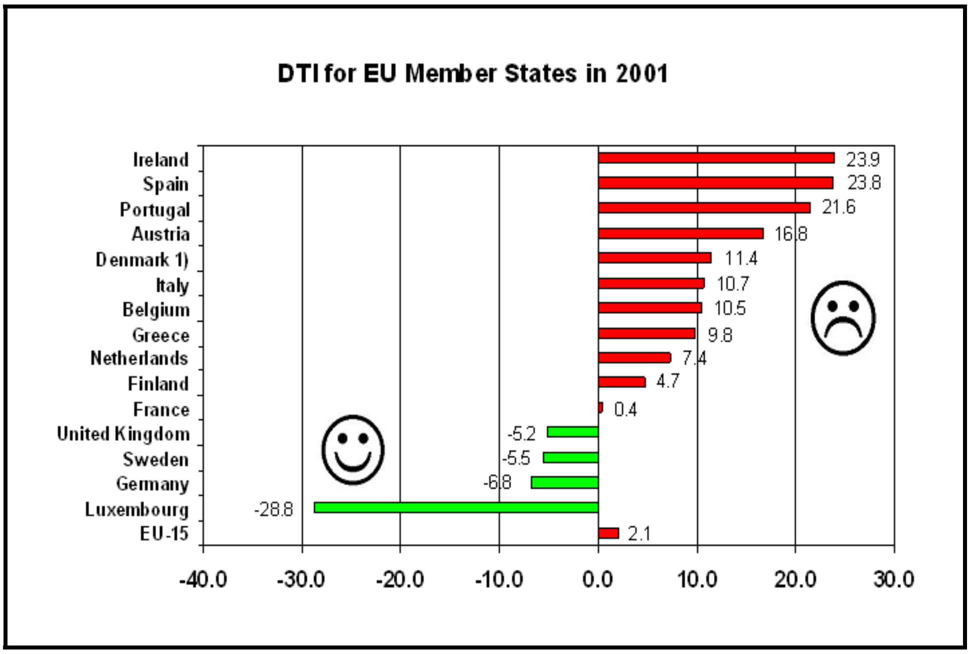


Figure 1: Total EU GHG emissions for 1990–2001 in relation to the Kyoto target for 2008–12. Source: EEA (2003).



[1)] The Danish DTI is +0.9 if Danish GHG emissions in the base year are adjusted for electricity trade (import and export) and for temperature variations.

Figure 2: Distance-to-target indicator (DTI) for EU Member States in 2001 (Kyoto Protocol and EU burden sharing targets). Source: Modified from EEA (2003).

Table 1: 2008–2012 targets for EU Member States under the Kyoto Protocol and EU burden sharing. Source: Modified from EEA (2003).

Member State	Base Year[a] (million tonnes)	2001 (million tonnes)	Change 2000–2001 (%)	Change Base Year–2001 (%)	Targets 2008–12 under EU burden sharing (%)
Austria	78.3	85.9	4.8	9.6	-13.0
Belgium	141.2	150.2	0.2	6.3	-7.5
Denmark[b]	69.5	69.4	1.8	-0.2 (-10.7)	-21.0
Finland	77.2	80.9	7.3	4.7	0.0
France	558.4	560.8	0.5	0.4	0.0
Germany	1216.2	993.5	1.2	-18.3	-21.0
Greece	107.0	132.2	1.9	23.5	25.0
Ireland	53.4	70.0	2.7	31.1	13.0
Italy	509.3	545.4	0.3	7.1	-6.5
Luxembourg	10.9	6.1	1.3	-44.2	-28.0
Netherlands	211.1	219.7	1.3	4.1	-6.0
Portugal	61.4	83.8	1.9	36.4	27.0
Spain	289.9	382.8	-1.1	32.1	15.0
Sweden	72.9	70.5	2.2	-3.3	4.0
United Kingdom	747.2	657.2	1.3	-12.0	-12.5
EU-15	4204.0	4108.3	1.0	-2.3	-8.0

[a] The base year for CO_2, CH_4 and N_2O is 1990; 1995 is used as the base year for fluorinated gases, as allowed for under the Kyoto Protocol. This reflects the preference of most Member States.
[b] For Denmark, data that reflect adjustments in 1990 for electricity trade (import and export) and for temperature variations are given in brackets. This methodology is used by Denmark to monitor progress towards its national target under the EU "burden sharing" agreement. For the EU emissions total non-adjusted Danish data have been used.

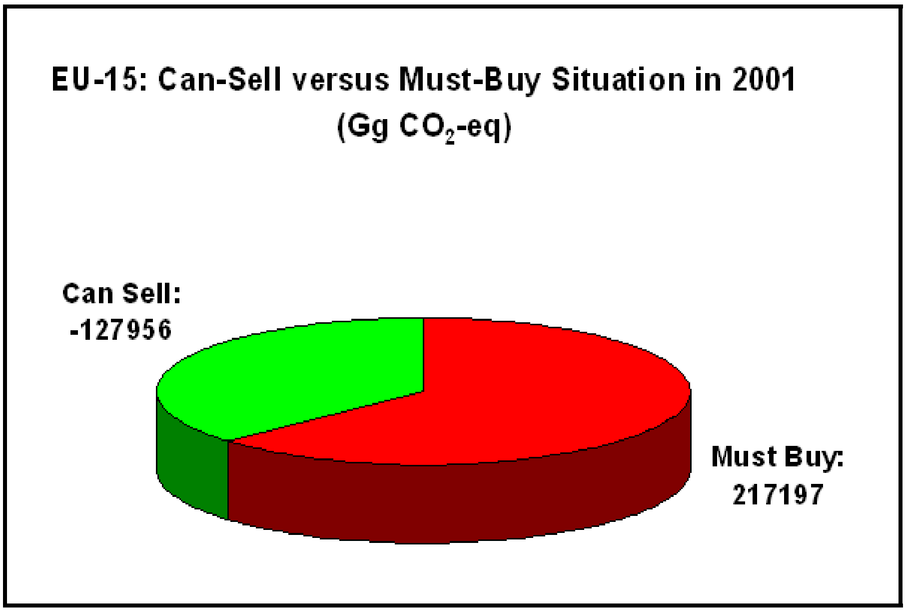


Figure 3: Figure 2 presented in absolute terms. Member States appearing as potential sellers in 2001: DE, LU, SE, UK; Member States appearing as potential buyers in 2001: AT, BE, DK, ES, FI, FR, GR, IE, IT, NL, PT. See ISO Country Code for country abbreviations and text for underlying assumptions.

The 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. The year of reference shall be 2001, the last year of the EU monitoring at the time of carrying out this study (EEA, 2003; Gugele *et al.*, 2003).

Uncertainties are extracted from the national inventory reports of the Member States and are monitored separately. However, a connection between emission and uncertainty estimates for the purpose of an advanced country evaluation has not yet been established. A recent compilation of uncertainties has been presented by Gugele *et al.* (2003:Table: 6) (see Table 2). This compilation makes available quantified uncertainty estimates from Austria, Finland, Netherlands and United Kingdom (total emissions and individual GHGs) and from Ireland (total emissions only). The uncertainties refer to a 95% confidence interval[3] and neglect, with the exception of the United Kingdom, emissions/removals due to land-use change and forestry (LUCF).[4]

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.

In Section 2 we recall the methodology of the Und&VT concept, which we apply in Section 3 with the above objective in mind. We interpret our results and present our conclusions in Section 4.

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

[4] In the case of Ireland, the CO_2 emissions arising from the liming of agricultural lands are not included under *Agriculture*, category 4 of the Revised 1996 IPCC Guidelines for National GHG Inventories (hereafter IPCC Guidelines; IPCC, 1997a, b, c), but they are accounted for under *Land Use Change and Forestry: CO_2 Emissions and Removals from Soil*, LUCF category 5D of the IPCC Guidelines. The IPCC Guidelines make allowance for the alternative source allocation in the case of this activity (McGettigan and Duffy, 2003:Sections 1.5 and 1.8).

Table 2: Overview of uncertainty estimates available from Member States (MS) excluding LUCF (with the exception of the United Kingdom). Source: Modified from Gugele *et al.* (2003:Table 6).

MS	**Uncertainty estimates extracted from Member States' national inventory reports**	**Source**
Austria[a]	Uncertainty analysis including systematic and random uncertainty was carried out for CO_2, CH_4 and N_2O for 1990 and 1997. The results of the calculations are as follows: Total uncertainty — CO_2 — CH_4 — N_2O — Total GHG emissions (excl. fluorinated gases) 1990 — 2.3% — 48.3% — 89.6% — 9.8% 1997 — 2.1% — 47.4% — 85.9% — 8.9%	Federal Environment Agency, Austria (2001)
Denmark	The national inventory report refers to Denmark's second national communication where the uncertainty of NMVOC, CH_4 and N_2O is assumed to be the highest (perhaps with an uncertainty factor 2). The uncertainty of CO and NO_x inventories is assumed to be less than 30–40% and the uncertainty of CO_2 may be as low as 1–2%. Applying the methodology mentioned in Annex 1 of the reporting instructions of the *Revised 1996 IPCC Guidelines for national GHG inventories* these estimates lead to an overall uncertainty of the GHG emissions in CO_2 equivalents of +/-23%. This estimate does not take into account the 35% uncertainty of the GWP-factors. Sensitivity analysis shows that it is the huge uncertainty of N_2O emissions from agricultural soils, which are the key factor for overall uncertainty of the Danish GHG inventory. Work is underway to implement uncertainty according to GPG. The results of this work are expected to be included in the Danish NIR 2004.	National Environmental Research Institute (2002)
Finland	In 2001 inventory, the uncertainty assessment was performed for the first time using the Monte Carlo simulation (Tier 2 method). The uncertainties in the input parameters were estimated using the IPCC default uncertainties, expert elicitation, domestic and international literature and available measurement data. A separate report on the uncertainty estimates (Monni and Syri 2003) will be published in 2003. According to the calculations, the uncertainty estimates for 2001 were as follows: Total GHGs — CO_2 — CH_4 — N_2O — Fluorinated gases -5/+6% — -4/+6% — -19/+20% — -33/+40% — -53/+32% The share of CO_2 emissions from fuel combustion, which has low uncertainties, is large in Finland, thus resulting in a rather low total inventory uncertainty, though some input parameters in other emission categories have very large uncertainties.	Ministry of the Environment (2003a)
France	Work is underway for estimating uncertainties of GHG emissions according to the *Good practice guidance* (IPCC, 2000). The uncertainties of CO_2 and SO_2 from energy use are assumed to be less than 5%.	CITEPA (2001)
Germany	The report states that partly emission uncertainties are considerable. This is due to uncertainties of activity data and emission factors and — to a much lesser extent — to a lack of information on emission-causing activities. In general, the uncertainty of combustion-related emissions is considerably lower than uncertainty of non-combustion-related emissions. The uncertainties are estimated to be higher for emissions after 1999 because they have to be considered as preliminary estimates. For qualitative estimates of emission uncertainties the report refers to the relevant CRF tables.	Bericht 2002 der Bundesrepublik Deutschland (2002)
Ireland	The Tier 1 method provided by IPCC (2000) has been used to make an uncertainty estimate of the Irish inventory time series for the years 1990–2000. This analysis results in an overall uncertainty of approximately 11% in the 2000 inventory of GHGs and a trend uncertainty of 5% for the period 1990 to 2000. This outcome is determined largely by the uncertainty in the estimate of N_2O emissions from agricultural soils, where an emission factor uncertainty of 100% is assumed in order to complete the analysis. This highlights the need for more reliable data on this particular emission source in Ireland. Two-thirds of total Irish emissions, i.e., the proportion contributed by CO_2, are estimated to have an uncertainty of less than 2%. When CH_4 is included, bringing the proportion up to 85%, the total uncertainty remains less than 4%, even though there are large uncertainties assigned to the CH_4 emission factors in most source categories. However, it is the influence of N_2O that leads to a substantial uncertainty in total emissions. This influence is not as large in the case of the trend, due to the modest change in emissions of N_2O from 1990 to 2000 and the relatively small share of this gas in total emissions. The impact of HFC, PFC and SF_6 on inventory uncertainty in the year 2000 is negligible because these gases account for less than 1% of total emissions.	Environmental Protection Agency (2002)
Netherlands	The Netherlands estimated uncertainty in annual emissions and in emission trends by applying the IPCC Tier 1 uncertainty approach at the level of the IPCC list of possible key sources. The results of the uncertainty estimates for 2000 CO_2 equivalent emissions is as follows: Total GHGs — CO_2 — CH_4 — N_2O — HFCs — PFCs — SF_6 ±4% — ±3% — ±25% — ±50% — ±50% — ±50% — ±50% The results of the uncertainty estimates for the trend 1990–2000 CO_2 equivalent emissions is as follows: Total GHGs — CO_2 — CH_4 — N_2O — Fluorinated gases ±3% — ±3% — ±7% — ±12% — ±11%	Olivier, J.G.J, Brandes, L.J., Peters, J.A.H.W. and Coenen, P.W.H.G. (2002)

Table 2: continued.

Spain	The Spanish report mentions that the assessment of uncertainty (estimation of emission quality) is shown in Table 7 of the CRF using the quality codes H (high), M (medium), and L (low). This ordinal classification of quality is only a first stage in the analysis of the uncertainty associated with the inventory estimations. Work is now in progress for the implementation of a quantitative estimation of uncertainty in accordance with the approach recommended in IPCC (2000).	Ministry of the Environment (2003b)
Sweden	The uncertainty in reported emissions arises from the uncertainty in the activity data, uncertainty in emission factors and uncertainty arising from whether all (major) sources of emissions are included in the inventory. For most sectors Swedish official statistics are used as activity data, except for industrial processes, emissions from F-gases and for solvent use where information comes from the industries annual environmental reports. Used emission factors originate either from measurements from existing Swedish plants or from comparable European installations, where IPCC default emission factors are not used. In 2003 validation of uncertainties for the emission estimates will be started. It is assumed that the uncertainty is largest for the inventories of CH_4 and N_2O, perhaps with an uncertainty factor of 2, for NMVOC, which have been recalculated possibly in the order of 50%, while the uncertainty on the CO, SO_2 and NO_x inventories is assumed to be less than 30–40% and the uncertainty with the CO_2 may be as low as 1–2%.	Swedish Environmental Protection Agency (2003)
United Kingdom	Quantitative estimates of the uncertainties in the emissions were calculated by using Monte Carlo simulation. This corresponds to the IPCC Tier 2 approach discussed in the *Good practice guidance* (IPCC, 2000). The results for the United Kingdom are as follows (calculated as 2s/E where s is the standard deviation and E is the mean, calculated in the simulation): (see table below) The Tier 1 approach based on the error propagation equations suggests an uncertainty of 17% in the combined GWP total emissions in 2001. The analysis also estimates an uncertainty of 2% in the trend between 1990 and 2000.	National Environmental Technology Centre (2003)

	Total GHGs	CO_2	CH_4	N_2O	HFCs	PFCs	SF_6
Emissions 2001 (%)	13	2.2	14	204	25	19	13
Range of likely percentage change (2001 and 1990)	-15/-10	-6.9/-4.2	-49/-31	-73/-17	-47/9	-76/-59	103/192

[a] Austria has, as the only Member State of the EU, 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 $CO_2 + CH_4 + N_2O$.

2 Methodology

We apply the Und&VT concept, which we have described in detail in Jonas *et al.* (2004). With the help of δ_{KP}, the normalized emission change under the EU burden sharing in compliance with the Kyoto Protocol,[5] and δ_{crit}, the critical (crit) emission limitation or reduction target, we distinguish the four cases listed in Table 3 and shown in Figure 4. The Member States' δ_{crit} values can be determined knowing the relative uncertainty (ρ) of their net emissions (see equation (32a,b) in Jonas *et al.*, 2004):

[5] 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, we continue to use δ_{KP} to avoid additional indexing.

$$\delta_{\text{crit}} = \begin{cases} \dfrac{\rho}{1+\rho} & \text{for} \quad x_2 < x_1 \;\; (\delta_{\text{KP}} > 0) \\[2ex] -\dfrac{\rho}{1-\rho} & \phantom{\text{for}} \quad x_2 \geq x_1 \;\; (\delta_{\text{KP}} \leq 0) \end{cases} , \qquad (1a,b)$$

where ρ is assumed to be symmetrical and, in line with preparatory signal detection, constant over time, i.e., $\rho(t_1) = \rho(t_2)$ with t_1 referring to the base year 1990[6] 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 we require 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: $\delta_{\text{KP}} > 0$	Case 1	$\delta_{\text{crit}} \leq \delta_{\text{KP}}$	Detectable EU/Kyoto target	
	Case 2	$\delta_{\text{crit}} > \delta_{\text{KP}}$	Non-detectable EU/Kyoto target: We apply an initial or obligatory undershooting so that the Member States' emission signals become detectable	
Emission Limitation: $\delta_{\text{KP}} \leq 0$	Case 3	$\delta_{\text{crit}} < \delta_{\text{KP}}$	Non-detectable EU/Kyoto target	We continue applying an initial or obligatory undershooting unconditionally for all Member States, before detectable reductions that Member States might have already realized (Case 4) are considered.
	Case 4	$\delta_{\text{crit}} \geq \delta_{\text{KP}}$	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 ($\delta_{\text{KP}} > 0$) and emission limitation ($\delta_{\text{KP}} \leq 0$) exhibit an over/undershooting dissimilarity (see Jonas *et al.*, 2004:Sections 3.1 and 3.2 for details).

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

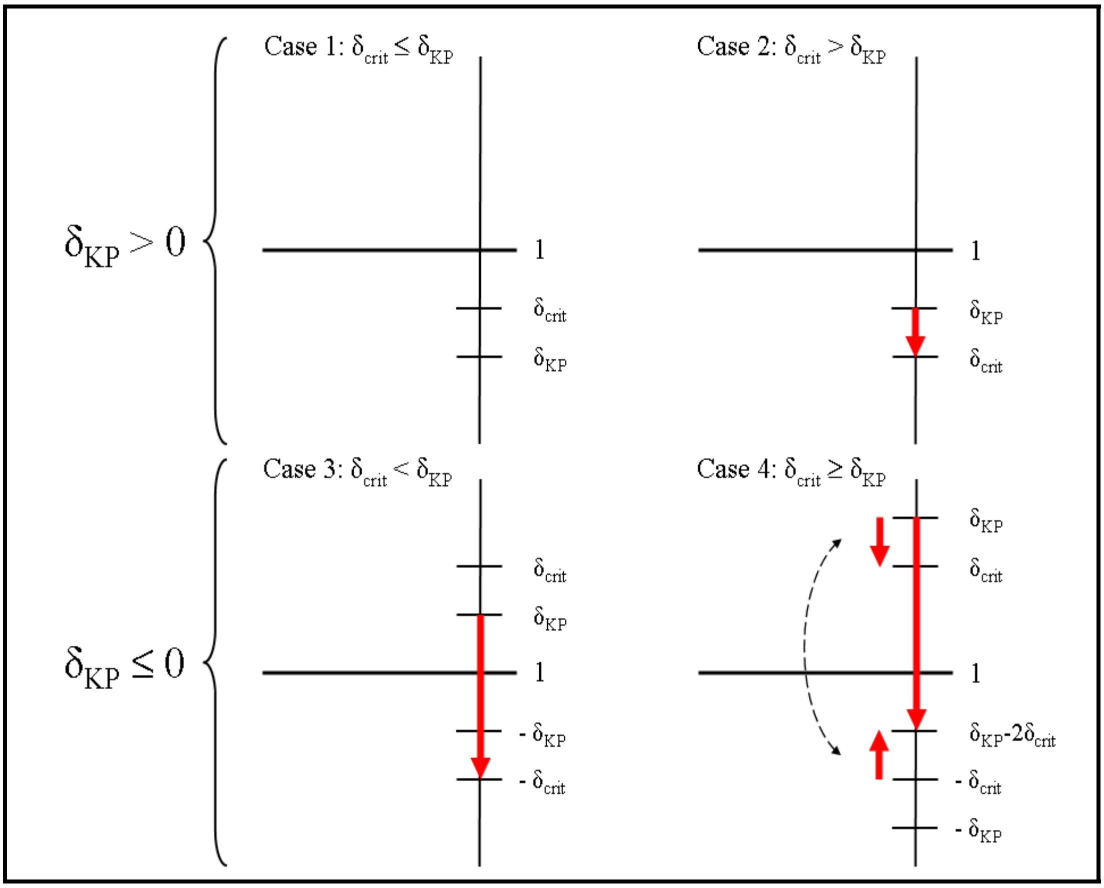

Figure 4: The four cases that are distinguished in applying the Und&VT concept (see also Table 3). Emission reduction: $\delta_{KP} > 0$; emission limitation: $\delta_{KP} \leq 0$.

<u>*Case 1: $\delta_{KP} > 0$: $\delta_{crit} \leq \delta_{KP}$.*</u> We make use of equations (43a), (B1), (D1), (B3) and (D2) of Jonas *et al.* (2004: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> We make use of equations (45a), (B1), (D3a,b), (D4) and (42b) of Jonas *et al.* (2004:Appendix D):

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

where

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

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

with

$$U_{Gap} = \delta_{crit} - \delta_{KP} \ . \tag{10}$$

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.* (2004:Section 3.4 and Appendix D) we replaced α by α_v (where "v" refers to "verifiable") in Cases 2–4, which we do not do 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 uncertainty of a Member State's net emissions
Derived:	
U	Undershooting Note: In Jonas *et al.* (2004:Section 3.4 and Appendix D) we replaced U by U_v (where "v" refers to "verifiable") in Cases 2–4, which we do not do 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 Nevertheless, we can grasp the risk α that $x_{t,2}$ is ≥ the true EU reference line (which is given, e.g., by $\left(1-\delta_{KP}\right)x_{t,1}$ in Case 1)

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

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

where

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

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

with

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

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

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

where

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

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

with

$$\mathrm{U}_{\mathrm{Gap}} = -2\delta_{\mathrm{crit}} \qquad (18)$$

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

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

3 Results

We proceed in two steps. In the first step we apply the Und&VT concept with reference to the time period base year–commitment year. With the knowledge of ρ, the relative uncertainty with which a Member State reports its net emissions and which we assume here to take on one of the values listed in Table 5, we can make use of Equation (1) and determine δ_{crit}, the Member State's critical emission limitation or reduction target.

Knowing 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), we can now compare the two and identify which Case applies to which Member State, that is, we identify the conditions that underlie the emission reporting of a particular Member State (and the EU as the whole) (see Table 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.* (2004: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, we will only consider the undershooting U in our 2$^{\mathrm{nd}}$-step investigation of the Member States' emission situation as of 2001.
In this second step, we take the U values reported in Table 8 and multiply them with the factor $(-11/20)$. The minus sign brings us in line with the emission reporting for the EU, which measures emission reductions negatively and emission increases positively (see Section 1). The factor $(11/20)$ establishes the base year–commitment year linear path undershooting targets for the year 2001 (see Table 9).

We interpret the results in the next section, together with our conclusions that we draw from this interpretation.

Table 5: The Member States' critical emission limitation or reduction targets (δ_{crit}) for assumed values of relative uncertainty (ρ), with which Member States report their net emissions (equation (1)).

	$\delta_{KP} > 0$	$\delta_{KP} \leq 0$		$\delta_{KP} > 0$	$\delta_{KP} \leq 0$
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: Identification of the conditions that underlie the emission reporting of a particular Member State (MS) and the EU as a whole in terms of Cases 1–4. Green: Detectable EU/Kyoto target (emission reduction). Orange: Detectable EU/Kyoto target (emission limitation). Red: Non detectable EU/Kyoto Target (emission limitation or reduction).

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
EC	**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 Member States (MS). The table lists the 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
EC	**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 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
EC	**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 $(-11/20)$ to reconcile the Und&VT concept with the emission reporting for the EU and to establish the base year–commitment year linear path undershooting targets for the year 2001.

MS	δ_{KP} %	α 1	Undershooting U in % for $\rho =$ 0%	2.5%	5%	7.5%	10%	15%	20%	30%	40%
AT	**-7.2**	0.0	0.0	-1.2	-2.3	-3.3	-4.4	-6.3	-9.7	-15.3	-19.8
		0.1	0.0	-0.9	-1.8	-2.7	-3.5	-5.1	-8.3	-13.7	-18.1
		0.2	0.0	-0.7	-1.4	-2.1	-2.7	-4.0	-6.9	-12.0	-16.2
		0.3	0.0	-0.5	-0.9	-1.4	-1.8	-2.7	-5.4	-10.1	-14.0
		0.4	0.0	-0.2	-0.5	-0.7	-0.9	-1.4	-3.8	-7.9	-11.5
		0.5	0.0	0.0	0.0	0.0	0.0	0.0	-2.0	-5.5	-8.6
BE	**-4.1**	0.0	0.0	-1.2	-2.4	-3.5	-5.4	-9.3	-12.7	-18.3	-22.8
		0.1	0.0	-1.0	-2.0	-2.9	-4.6	-8.2	-11.4	-16.8	-21.1
		0.2	0.0	-0.8	-1.5	-2.2	-3.7	-7.0	-10.0	-15.0	-19.2
		0.3	0.0	-0.5	-1.0	-1.5	-2.8	-5.8	-8.4	-13.1	-17.0
		0.4	0.0	-0.3	-0.5	-0.8	-1.9	-4.4	-6.8	-11.0	-14.5
		0.5	0.0	0.0	0.0	0.0	-0.9	-3.0	-5.0	-8.6	-11.6
DK	**-11.6**	0.0	0.0	-1.1	-2.1	-3.0	-4.0	-5.7	-7.2	-10.9	-15.4
		0.1	0.0	-0.9	-1.7	-2.5	-3.2	-4.7	-6.0	-9.3	-13.7
		0.2	0.0	-0.6	-1.3	-1.9	-2.5	-3.6	-4.7	-7.6	-11.8
		0.3	0.0	-0.4	-0.9	-1.3	-1.7	-2.5	-3.2	-5.7	-9.6
		0.4	0.0	-0.2	-0.4	-0.6	-0.9	-1.3	-1.7	-3.5	-7.1
		0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.1	-4.2
FI	**0.0**	0.0	0.0	-2.7	-5.4	-8.0	-10.6	-15.6	-20.6	-30.8	-41.9
		0.1	0.0	-2.5	-4.9	-7.3	-9.7	-14.6	-19.4	-29.7	-41.1
		0.2	0.0	-2.2	-4.4	-6.6	-8.9	-13.4	-18.2	-28.4	-40.2
		0.3	0.0	-1.9	-3.9	-5.9	-8.0	-12.3	-16.8	-26.9	-39.2
		0.4	0.0	-1.7	-3.4	-5.2	-7.1	-11.0	-15.3	-25.4	-38.0
		0.5	0.0	-1.4	-2.9	-4.5	-6.1	-9.7	-13.8	-23.6	-36.7
FR	**0.0**	0.0	0.0	-2.7	-5.4	-8.0	-10.6	-15.6	-20.6	-30.8	-41.9
		0.1	0.0	-2.5	-4.9	-7.3	-9.7	-14.6	-19.4	-29.7	-41.1
		0.2	0.0	-2.2	-4.4	-6.6	-8.9	-13.4	-18.2	-28.4	-40.2
		0.3	0.0	-1.9	-3.9	-5.9	-8.0	-12.3	-16.8	-26.9	-39.2
		0.4	0.0	-1.7	-3.4	-5.2	-7.1	-11.0	-15.3	-25.4	-38.0
		0.5	0.0	-1.4	-2.9	-4.5	-6.1	-9.7	-13.8	-23.6	-36.7
DE	**-11.6**	0.0	0.0	-1.1	-2.1	-3.0	-4.0	-5.7	-7.2	-10.9	-15.4
		0.1	0.0	-0.9	-1.7	-2.5	-3.2	-4.7	-6.0	-9.3	-13.7
		0.2	0.0	-0.6	-1.3	-1.9	-2.5	-3.6	-4.7	-7.6	-11.8
		0.3	0.0	-0.4	-0.9	-1.3	-1.7	-2.5	-3.2	-5.7	-9.6
		0.4	0.0	-0.2	-0.4	-0.6	-0.9	-1.3	-1.7	-3.5	-7.1
		0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.1	-4.2
GR	**13.8**	0.0	0.0	-4.4	-8.8	-13.1	-17.4	-25.8	-34.4	-44.6	-55.7
		0.1	0.0	-4.1	-8.2	-12.3	-16.4	-24.7	-33.2	-43.4	-54.9
		0.2	0.0	-3.8	-7.6	-11.5	-15.4	-23.5	-31.9	-42.1	-54.0
		0.3	0.0	-3.5	-7.0	-10.7	-14.4	-22.2	-30.6	-40.7	-52.9
		0.4	0.0	-3.1	-6.4	-9.8	-13.3	-20.8	-29.1	-39.1	-51.8
		0.5	0.0	-2.8	-5.8	-8.9	-12.2	-19.4	-27.5	-37.3	-50.4

Table 9: continued.

IE	**7.2**	0.0	0.0	-4.3	-8.5	-12.6	-16.8	-22.8	-27.8	-38.0	-49.1
		0.1	0.0	-4.0	-8.0	-11.9	-15.9	-21.7	-26.6	-36.8	-48.3
		0.2	0.0	-3.7	-7.4	-11.2	-15.0	-20.6	-25.3	-35.5	-47.4
		0.3	0.0	-3.4	-6.9	-10.5	-14.1	-19.4	-24.0	-34.1	-46.3
		0.4	0.0	-3.1	-6.3	-9.7	-13.2	-18.2	-22.5	-32.5	-45.2
		0.5	0.0	-2.8	-5.8	-8.9	-12.2	-16.9	-20.9	-30.7	-43.8
IT	**-3.6**	0.0	0.0	-1.3	-2.4	-3.8	-6.0	-9.8	-13.2	-18.9	-23.4
		0.1	0.0	-1.0	-2.0	-3.2	-5.1	-8.7	-11.9	-17.3	-21.7
		0.2	0.0	-0.8	-1.5	-2.5	-4.3	-7.5	-10.5	-15.6	-19.7
		0.3	0.0	-0.5	-1.0	-1.8	-3.3	-6.3	-9.0	-13.7	-17.6
		0.4	0.0	-0.3	-0.5	-1.0	-2.4	-5.0	-7.4	-11.5	-15.0
		0.5	0.0	0.0	0.0	-0.3	-1.4	-3.6	-5.6	-9.1	-12.1
LU	**-15.4**	0.0	0.0	-1.0	-1.9	-2.8	-3.6	-5.2	-6.6	-9.1	-11.5
		0.1	0.0	-0.8	-1.5	-2.2	-2.9	-4.2	-5.5	-7.7	-9.8
		0.2	0.0	-0.6	-1.2	-1.7	-2.2	-3.3	-4.2	-6.0	-7.9
		0.3	0.0	-0.4	-0.8	-1.2	-1.5	-2.2	-2.9	-4.2	-5.7
		0.4	0.0	-0.2	-0.4	-0.6	-0.8	-1.2	-1.5	-2.2	-3.2
		0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.3
NL	**-3.3**	0.0	0.0	-1.3	-2.5	-4.1	-6.2	-10.1	-13.5	-19.2	-23.6
		0.1	0.0	-1.0	-2.0	-3.4	-5.4	-9.0	-12.2	-17.6	-21.9
		0.2	0.0	-0.8	-1.5	-2.7	-4.5	-7.8	-10.8	-15.8	-20.0
		0.3	0.0	-0.5	-1.0	-2.0	-3.6	-6.6	-9.3	-13.9	-17.8
		0.4	0.0	-0.3	-0.5	-1.3	-2.7	-5.3	-7.6	-11.8	-15.3
		0.5	0.0	0.0	0.0	-0.5	-1.7	-3.9	-5.9	-9.4	-12.4
PT	**14.9**	0.0	0.0	-4.5	-8.8	-13.2	-17.5	-26.0	-34.6	-45.7	-56.8
		0.1	0.0	-4.1	-8.3	-12.4	-16.5	-24.8	-33.3	-44.5	-56.0
		0.2	0.0	-3.8	-7.7	-11.5	-15.5	-23.6	-32.0	-43.2	-55.1
		0.3	0.0	-3.5	-7.0	-10.7	-14.4	-22.3	-30.6	-41.8	-54.0
		0.4	0.0	-3.2	-6.4	-9.8	-13.4	-20.9	-29.1	-40.2	-52.9
		0.5	0.0	-2.8	-5.8	-8.9	-12.2	-19.4	-27.5	-38.4	-51.5
ES	**8.3**	0.0	0.0	-4.3	-8.5	-12.7	-16.9	-23.9	-28.9	-39.1	-50.2
		0.1	0.0	-4.0	-8.0	-12.0	-16.0	-22.8	-27.7	-37.9	-49.4
		0.2	0.0	-3.7	-7.5	-11.3	-15.1	-21.7	-26.4	-36.6	-48.5
		0.3	0.0	-3.4	-6.9	-10.5	-14.2	-20.5	-25.1	-35.2	-47.4
		0.4	0.0	-3.1	-6.4	-9.7	-13.2	-19.3	-23.6	-33.6	-46.3
		0.5	0.0	-2.8	-5.8	-8.9	-12.2	-18.0	-22.0	-31.8	-44.9
SE	**2.2**	0.0	0.0	-4.1	-7.6	-10.2	-12.8	-17.8	-22.8	-33.0	-44.1
		0.1	0.0	-3.9	-7.1	-9.5	-11.9	-16.8	-21.6	-31.9	-43.3
		0.2	0.0	-3.6	-6.6	-8.8	-11.1	-15.6	-20.4	-30.6	-42.4
		0.3	0.0	-3.4	-6.1	-8.1	-10.2	-14.5	-19.0	-29.1	-41.4
		0.4	0.0	-3.1	-5.6	-7.4	-9.3	-13.2	-17.5	-27.6	-40.2
		0.5	0.0	-2.8	-5.1	-6.7	-8.3	-11.9	-16.0	-25.8	-38.9
UK	**-6.9**	0.0	0.0	-1.2	-2.3	-3.4	-4.4	-6.5	-9.9	-15.6	-20.1
		0.1	0.0	-0.9	-1.9	-2.7	-3.6	-5.4	-8.6	-14.0	-18.4
		0.2	0.0	-0.7	-1.4	-2.1	-2.7	-4.2	-7.2	-12.3	-16.4
		0.3	0.0	-0.5	-0.9	-1.4	-1.9	-3.0	-5.7	-10.4	-14.3
		0.4	0.0	-0.2	-0.5	-0.7	-0.9	-1.7	-4.1	-8.2	-11.7
		0.5	0.0	0.0	0.0	0.0	0.0	-0.3	-2.3	-5.8	-8.8
EC	**-4.4**	**0.0**	**0.0**	**-1.2**	**-2.4**	**-3.5**	**-5.1**	**-9.0**	**-12.4**	**-18.1**	**-22.5**
		0.1	**0.0**	**-1.0**	**-1.9**	**-2.9**	**-4.3**	**-7.9**	**-11.1**	**-16.5**	**-20.8**
		0.2	**0.0**	**-0.7**	**-1.5**	**-2.2**	**-3.4**	**-6.7**	**-9.7**	**-14.7**	**-18.9**
		0.3	**0.0**	**-0.5**	**-1.0**	**-1.5**	**-2.5**	**-5.5**	**-8.2**	**-12.8**	**-16.7**
		0.4	**0.0**	**-0.3**	**-0.5**	**-0.7**	**-1.6**	**-4.2**	**-6.5**	**-10.7**	**-14.2**
		0.5	**0.0**	**0.0**	**0.0**	**0.0**	**-0.6**	**-2.8**	**-4.8**	**-8.3**	**-11.3**

4 Interpretation of Results and Conclusions

To interpret the results for 2001, we display:

(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, we follow Jonas and Nilsson (2001), who recommended in their earlier study 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. We proceed similarly with respect to α.

The DTI displayed in Figure 2 is always shown to contrast the Member States' linear path undershooting targets for the year 2001 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 $(-11/20)$). U_{Gap} is the initial or obligatory undershooting that is required to achieve detectability before the Member States are permitted to make use of their 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, LU, SE and the UK (Figure 2). Given $\alpha = 0.5$, LU is the best potential seller followed by DE, the UK and SE. Both LU and DE can report with relative uncertainties > 40%, LU even with a relative uncertainty >> 40%, and still exhibit detectable emission signals, while the UK and SE must report with a relative uncertainty falling into the interval $[20,40[$ (more correctly: up to approximately 28%) and $[5,10[$ % (more correctly: up to approximately 6%), respectively.

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 $\alpha = 0.0$, only LU can still report with a relative uncertainty > 40% without compromising the detectability of its emission signal, while DE and the UK must report with a relative uncertainty falling into the interval $[10, 20[$ (more correctly: up to approximately 18 and 12%, respectively) and SE even with a relative uncertainty falling into the interval $[0, 5[$ % (more correctly: up to approximately 3%).

(II) U by α 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 ($-11/20$) 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 our 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 $U_{Gap} < 0$, eventually even LU (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. Figures 12–14 still resolve U_{Gap} better than the remainder of U.

We prefer interpretation I (U by ρ with α as a parameter; Figures 5–10) 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. (SE, e.g., meets U_{Gap} for $\rho = 5\%$ but not any more for $\rho = 10\%$; Figures 11 and 12.)

The following four conclusions emerge from our exercise:

(1) Jonas *et al.* (2004) 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 we apply one of these techniques, the Und&VT concept, to the Member States of the European Union under the EU burden sharing in compliance with the Kyoto Protocol, but with reference to the base year–commitment year linear path undershooting targets in 2001. Thus, our exercise shows that preparatory signal detection can also be applied in connection with interim emission targets.

(2) To advance the reporting of the EU we take, in addition to the DTI, uncertainty and its consequences into consideration, i.e., we determine (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. We anticipate 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 2001 only four Member States exhibit a negative DTI and thus appear as potential sellers: DE, LU, 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 emissions/removals due to LUCF (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 by the three Member States: DE, LU and the UK — or LU, DE and the UK if ranked in terms of creditability (Figure 9). Within the 5–10% relative uncertainty class, SE can only act as a potential high-risk seller (Figure 5).

(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 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 (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.*, 2004:Section 3.1); these are 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.

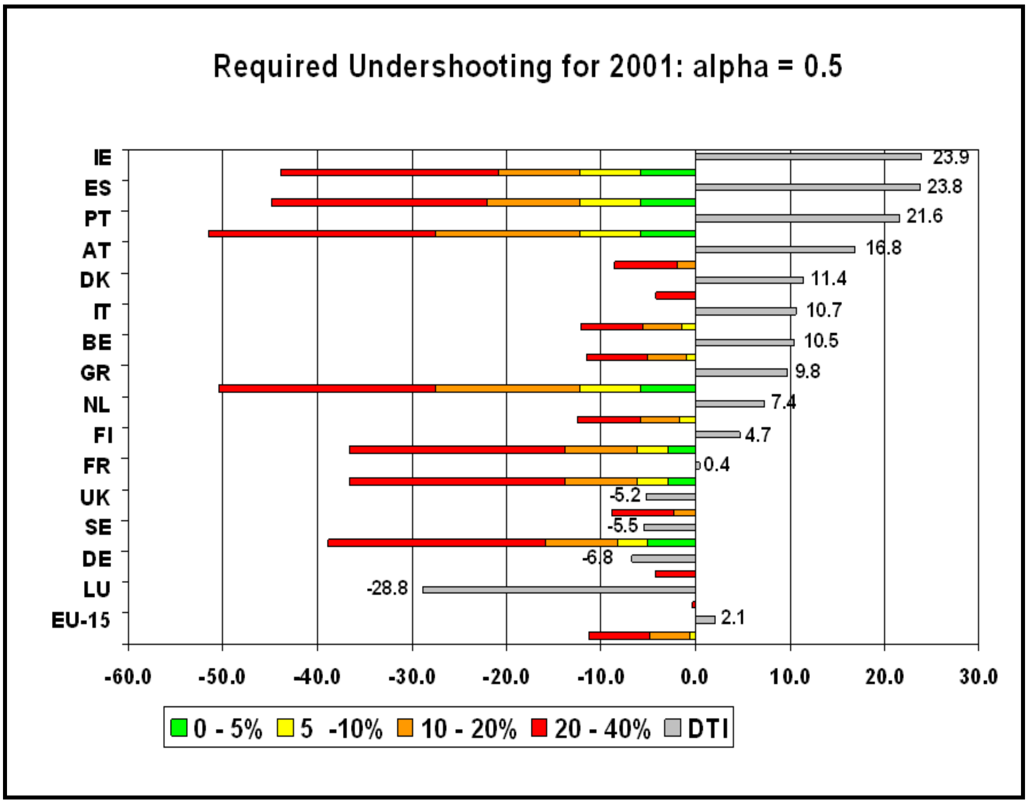

Figure 5: U by ρ (see intervals) for $\alpha = 0.5$ in addition to the DTI.

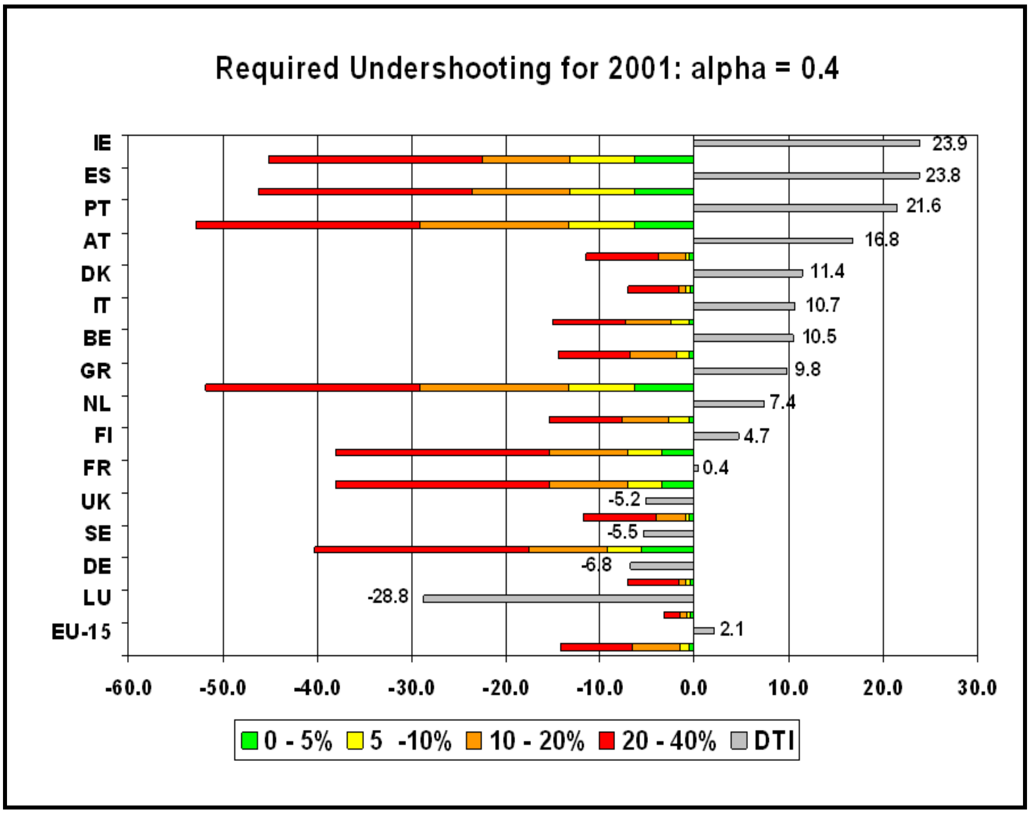

Figure 6: U by ρ (see intervals) for $\alpha = 0.4$ in addition to the DTI.

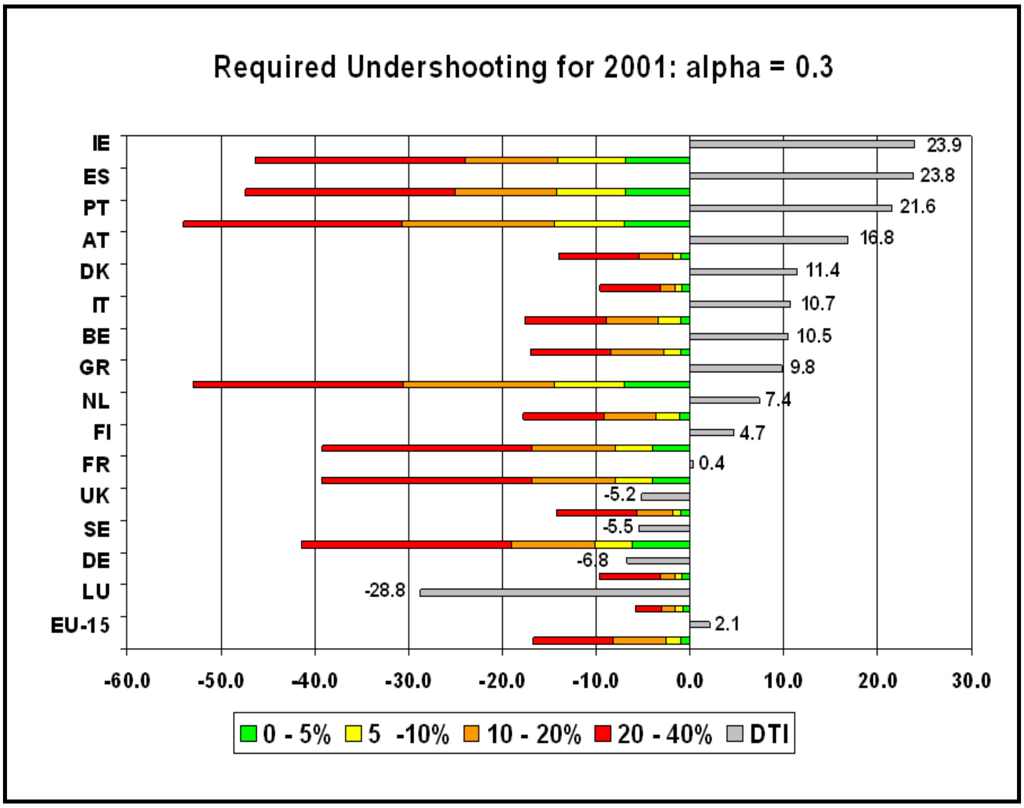

Figure 7: U by ρ (see intervals) for $\alpha = 0.3$ in addition to the DTI.

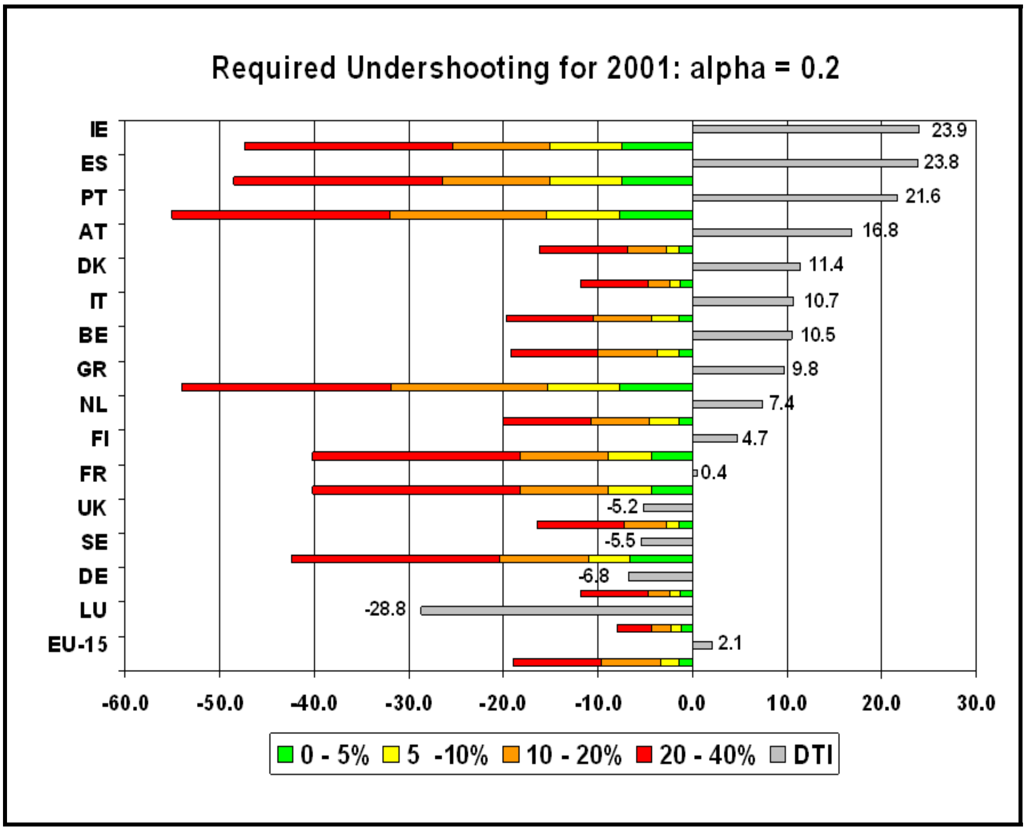

Figure 8: U by ρ (see intervals) for $\alpha = 0.2$ in addition to the DTI.

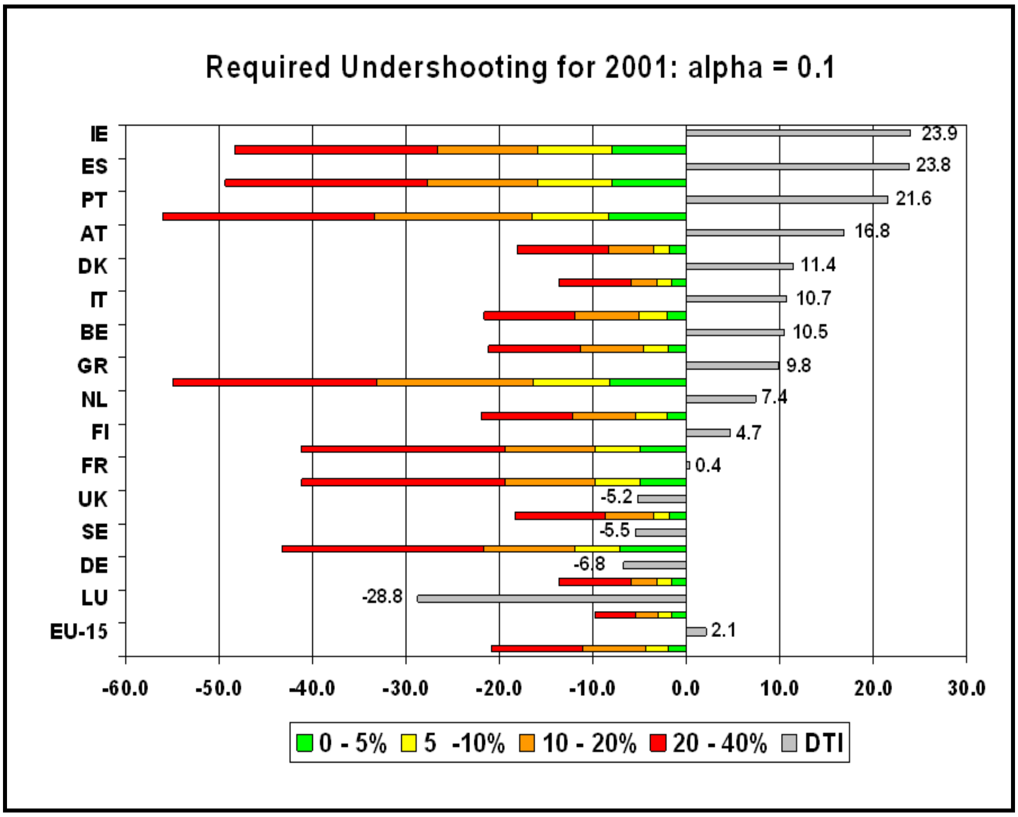

Figure 9: U by ρ (see intervals) for $\alpha = 0.1$ in addition to the DTI.

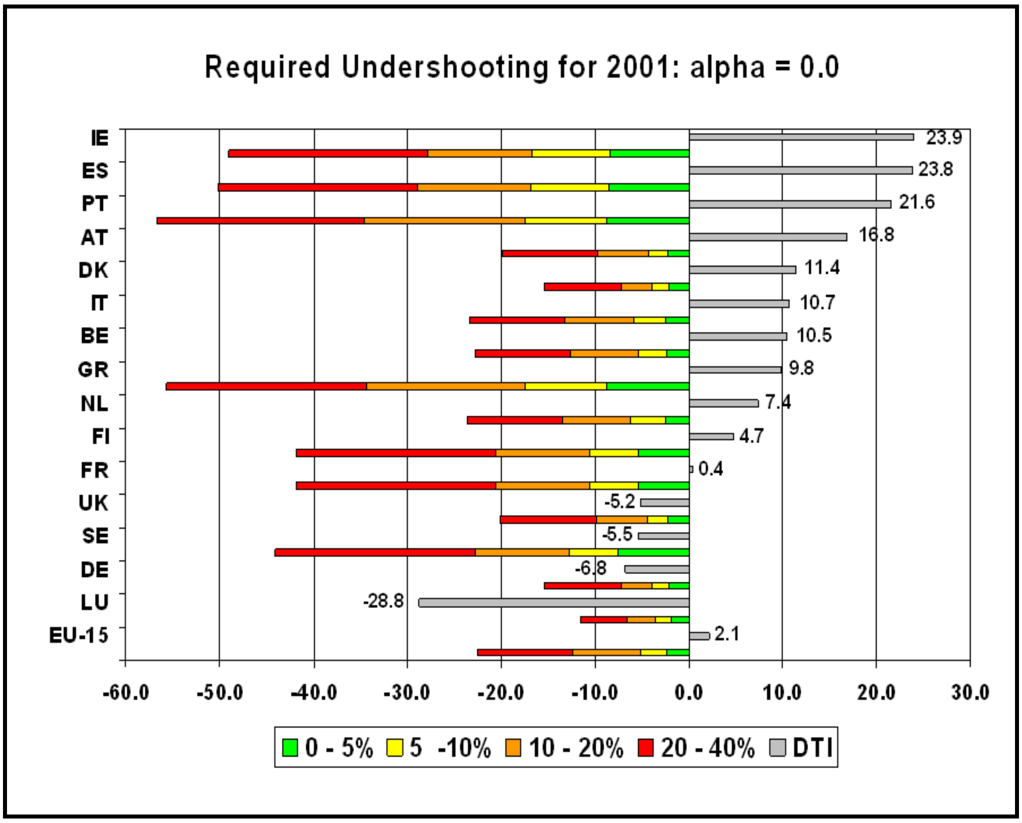

Figure 10: U by ρ (see intervals) for $\alpha = 0.0$ in addition to the DTI.

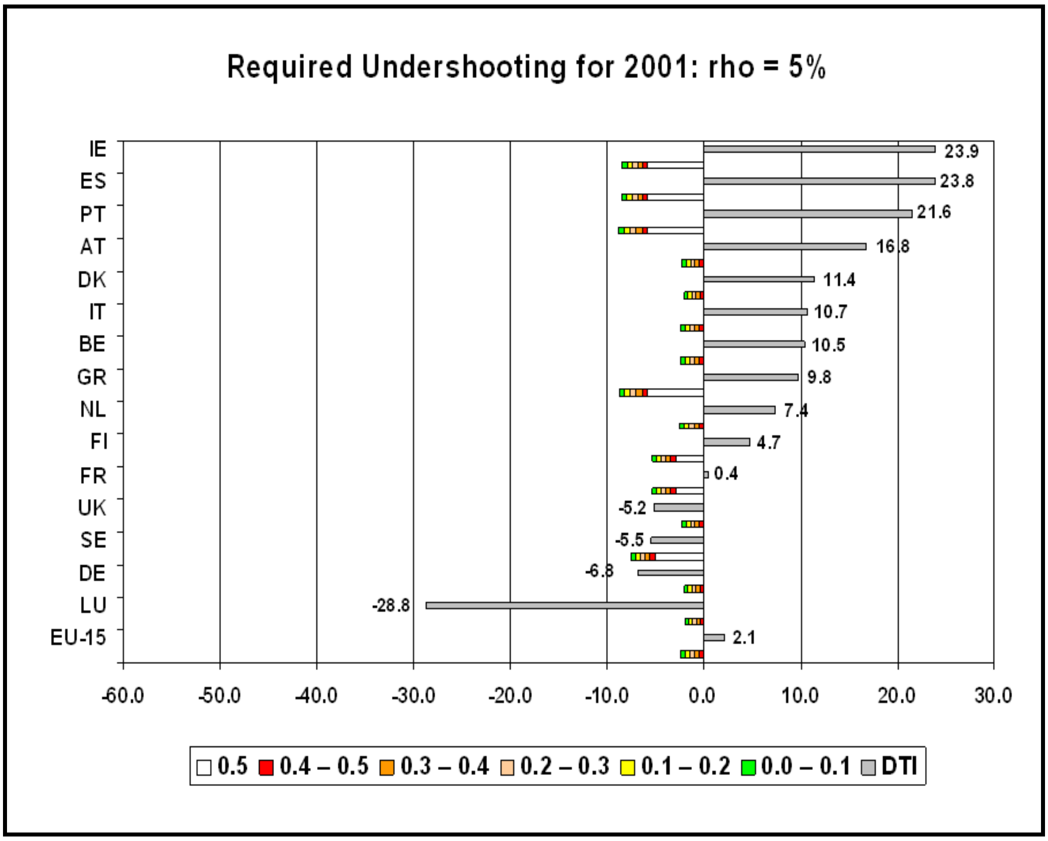

Figure 11: U by α (see value and intervals) for $\rho = 5\%$ in addition to the DTI.

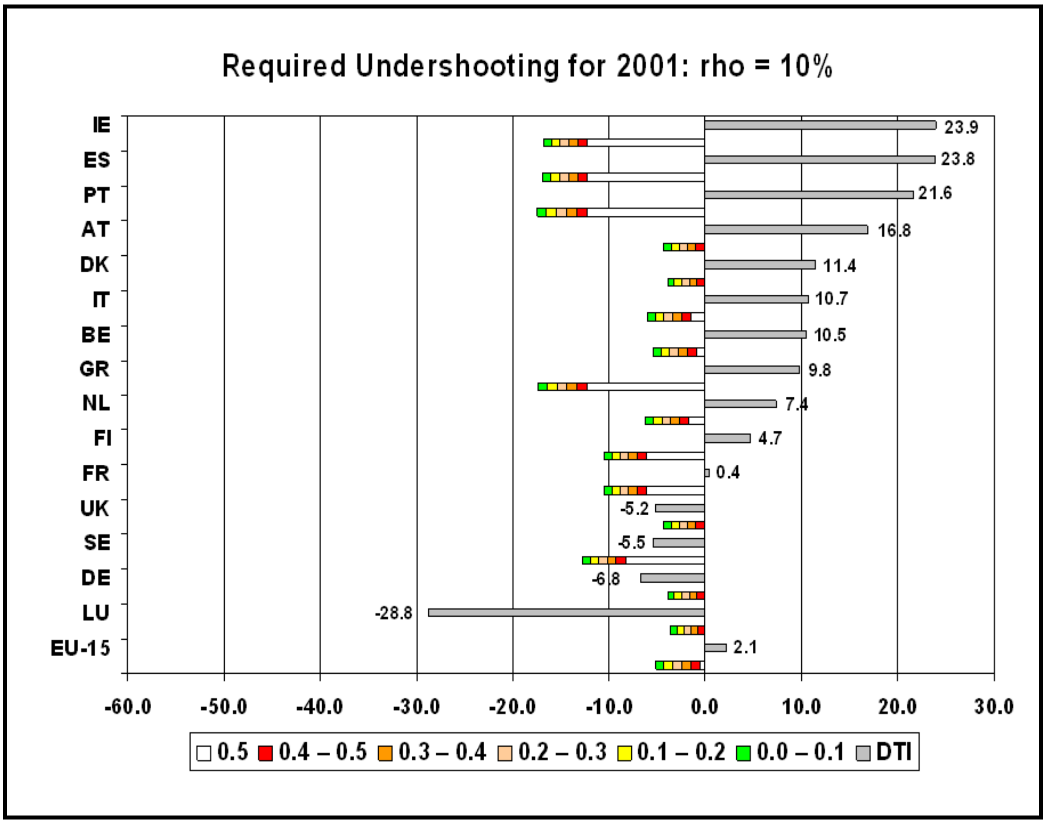

Figure 12: U by α (see value and intervals) for $\rho = 10\%$ in addition to the DTI.

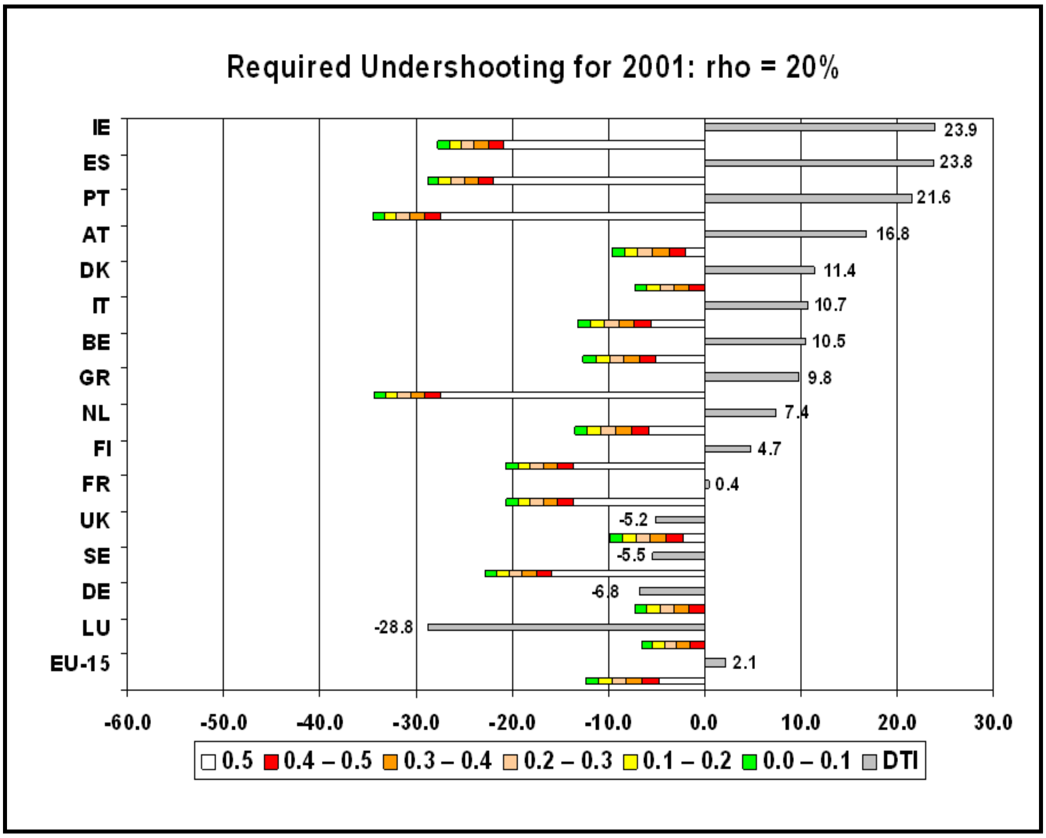

Figure 13: U by α (see value and intervals) for $\rho = 20\%$ in addition to the DTI.

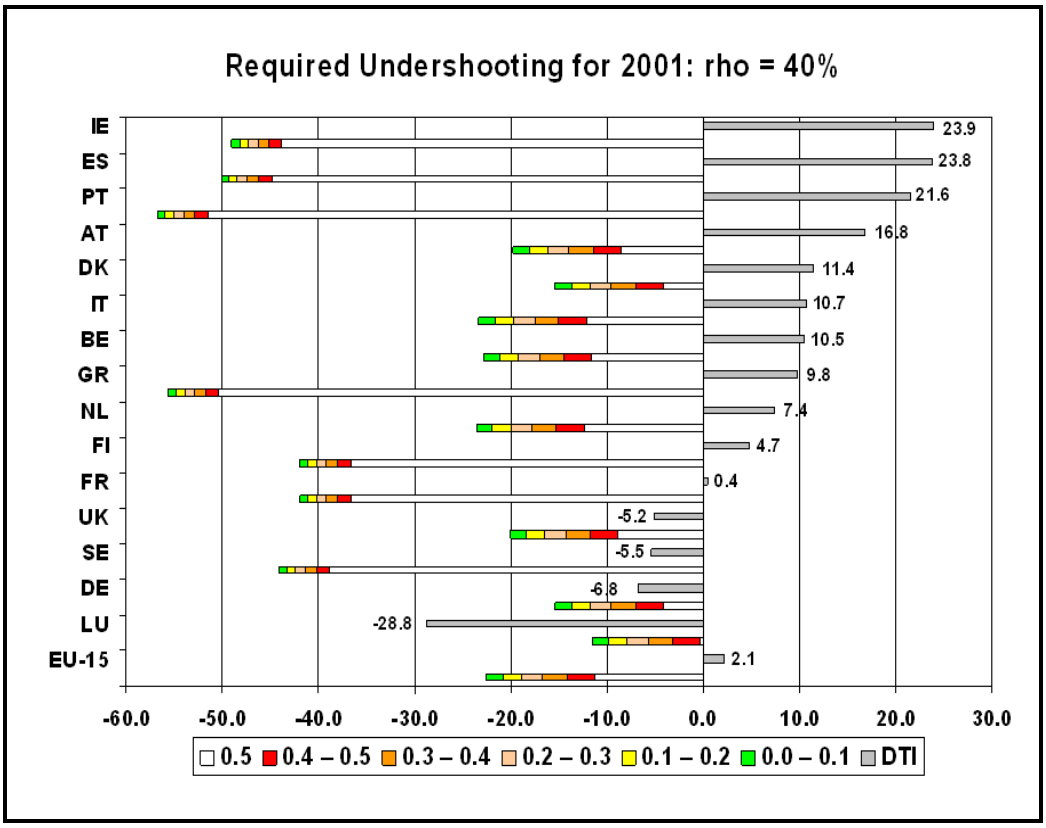

Figure 14: U by α (see value and intervals) for $\rho = 40\%$ in addition to the DTI.

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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
EC	European Community
ES	Spain
FI	Finland
FR	France
GR	Greece
IE	Ireland
IT	Italy
LU	Luxembourg
NL	Netherlands
PT	Portugal
SE	Sweden
UK	United Kingdom