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Preparatory Signal Detection for the EU-27 Member States Under EU Burden Sharing—Advanced Monitoring Including Uncertainty (1990–2007)

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Contents

Abstract

This study follows up 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 B countries as net emitters and referred to all Kyoto GHGs (CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6) 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 uncertainty estimates for the purpose of an advanced country evaluation has not yet been established. The authors developed four preparatory signal analysis techniques and applied these to the Annex B countries under the Kyoto Protocol. The frame of reference for preparatory signal detection is that Annex B countries comply with their agreed emission targets in 2008–2012. The emissions path between base year and commitment year/period is generally assumed to be a straight line, and emissions prior to the base year are not taken into consideration. An in-depth quantitative comparison of the four, plus two additional, preparatory signal analysis techniques has been prepared by Jonas *et al.* (2010).

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 27 Member States of the European Union (EU). In contrast to the study by Jonas *et al.* (2004), the Member States' agreed emission targets under 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' agreed 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 2007.

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 (true emission target); and (ii) the detectability of the Member State's agreed emission target. This risk can be grasped and quantified although true emissions are unknown by definition. Undershooting the agreed target or the compatible but detectable target can decrease this risk. The Member States' undershooting options and challenges as of 2007 are contrasted with their actual emission situation in that year, which is captured by the

distance-to-target-path indicator (DTPI; formerly: distance-to-target indicator) initially introduced by the European Environment Agency. This indicator measures by how much the emissions of a Member State deviate from its linear emissions path between base year and target year.

In 2007, fourteen EU-27 Member States exhibit a negative DTPI and thus appear as potential sellers: Belgium, Bulgaria, Czech Republic, Estonia, France, Germany, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, Sweden, and the United Kingdom. However, expecting that all of the EU Member States will eventually 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 ($\alpha \approx 0.1$) that the Member States' true emissions in the commitment year/period fall above their true emission targets. As of 2007, these conditions can only be met by ten (nine new and one old) Member States (ranked in terms of credibility): Latvia, Lithuania, Estonia, Romania, Bulgaria, Slovakia, Hungary, Poland, the Czech Republic and the United Kingdom; while four Member States, Germany, Belgium, Sweden and France, can only act as potential sellers with a higher risk (Germany: $\alpha \approx 0.1$; Belgium: $\alpha \approx 0.3$; Sweden: $\alpha \approx 0.4$, France: $\alpha = 0.5$). The other EU-27 Member States do not meet their linear path (base year–commitment year) undershooting targets as of 2007 (i.e., they overshoot their intermediate targets), or do not have Kyoto targets at all (Cyprus and Malta).

The relative uncertainty, with which countries report their emissions, matters. For instance, with relative uncertainty increasing from 5 to 10%, the 2008/12 emission reduction of the EU-15 as a whole (which has jointly approved, as a Party, an 8% emission reduction under the Kyoto Protocol) 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.

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.

About the Authors

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Preparatory Signal Detection for the EU-27 Member States Under EU Burden Sharing—Advanced Monitoring Including Uncertainty (1990–2007)

Myroslava Lesiv, Andriy Bun, Khrystyna Hamal and Matthias Jonas

1 Background and Objective

This study follows up IIASA Interim Report IR-04-024 (Jonas *et al.*, 2004). 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 27 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 SF_6) excluding CO_2 emissions/removals due to land-use change and forestry (LUCF). The Member States' emissions are evaluated relative to their linear path targets as of 2007 and in terms of their positive and negative contributions to these targets.[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-27 as a whole, of trends in emissions of GHGs up to 2007. The EU-15 as a whole is shown separately, as it was the old EU Member States that have jointly approved, as a Party, the Kyoto Protocol to the United Nations Framework on Climate Change (EU Official Journal, 2002: Annex II). Figure 1 follows the total emissions of the EU over time since 1990, while the distance-to-target-path indicator (DTPI; formerly: distance-to-target indicator) introduced in Figure 2, based on the country data listed in Table 1, is a measure for how much the Member States' actual (2007) GHG emissions deviate from their linear target paths between 1990 and 2008–2012, assuming that only domestic measures will be used (i.e., excluding Kyoto mechanisms). A negative DTPI 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, 2009a: Tab. ES.3 and 2.3; EEA, 2009b: Fig. 6.2 and Tab. 12.1).[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 2007 and their linear path targets for that year. Figure 3 facilitates understanding the 2007 situation of the EU in quantitative terms.

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 (true emissions target); and (ii) the detectability of the Member State's agreed emission target. This risk can be grasped and quantified although true emissions are unknown by definition (but not necessarily their ratios). Undershooting the agreed target or the compatible but detectable target can decrease this risk. Here, the intermediate year of reference in the focus of attention is 2007, i.e., the linear target path 1990–2008/12 is evaluated with respect to this year.

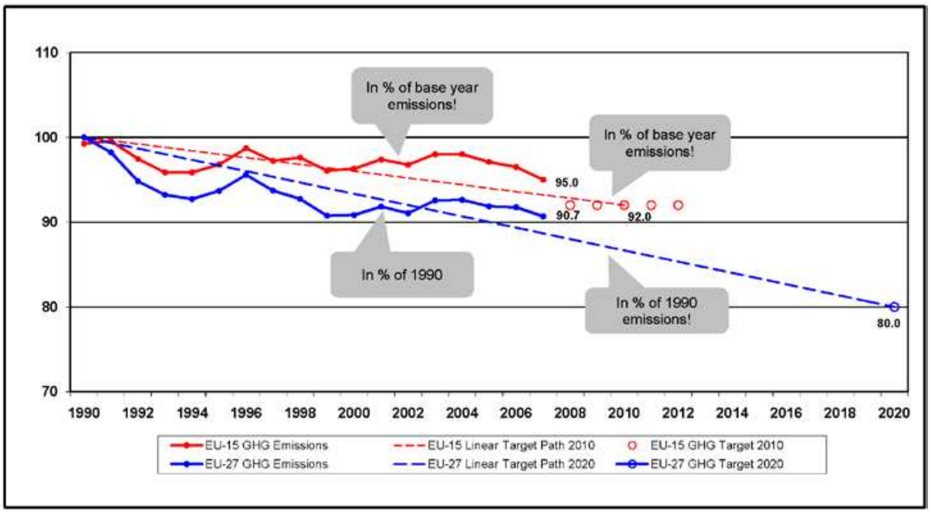

Figure 1: EU-27 GHG emissions for 1990–2007 (excluding LUCF and Kyoto mechanisms) with 1990 emissions as reference. The corresponding EU-15 GHG emissions and linear target path 1990–2008/12, with base-year emissions as reference, are shown for comparison. Source: EEA (2009a: Fig. ES.1 and ES.2; reproduced).

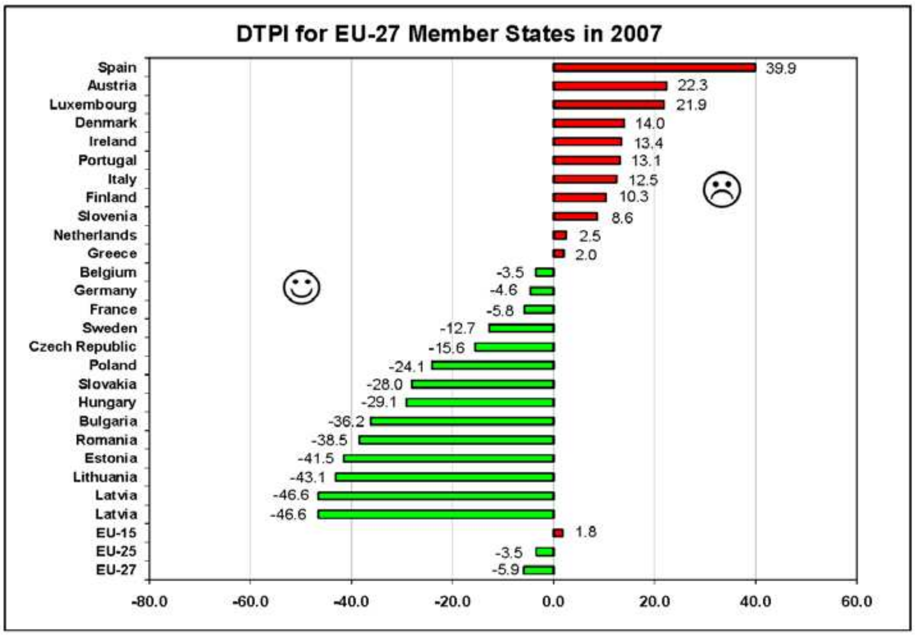

Figure 2: Distance-to-target-path indicator (DTPI) for EU-27 as a whole and its Member States in 2007 under the Kyoto Protocol and EU burden sharing (excluding LUCF and Kyoto mechanisms). The DTPIs for the EU-15 and EU-25 as a whole are shown for comparison.

Table 1: Gap (2003/07–Kyoto target; given by the sum of % values in the 1st and 3rd column from the right) for the EU-27 as a whole and its Member States in 2008/12 under the Kyoto Protocol and EU burden sharing (excluding LUCF and Kyoto mechanisms). This gap indicator is identical to the distance-to-target-path indicator (DTPI) with reference to 2008/12, not 2007 which is not reported by the EEA. 3rd and 4th column: base year and 1990 GHG emissions (in CO_2-equivalent); 5th and 6th column: 2007 and 2008 GHG emissions (in CO_2-equivalent and % relative to base year); 7th and 8th column: 2003–2007 and 2004–2008 mean GHG emissions (in CO_2-equivalent and % relative to base year). Values for the EU-15 as a whole are shown for comparison. Sources: EEA (2009a: Fig. 6.2 and Table 12.1).

Country	Unit	Kyoto base-year	1990	2007	2008 (b)	2003–2007 average	2004–2008 average (b)	2008–2012 Kyoto target
Austria	Mt CO_2-equivalent	79.0	79.0	88.0	-	91.4	-	68.8
	% from base year			11.3 %	-	15.7 %	-	– 13.0 %
Belgium	Mt CO_2-equivalent	145.7	143.2	131.3	-	140.3	-	134.8
	% from base year			– 9.9 %	-	– 3.8 %	-	– 7.5 %
Denmark	Mt CO_2-equivalent	69.3	69.1	66.6	63.5	68.5	66.5	54.8
	% from base year			– 3.9 %	– 8.4 %	– 1.1 %	– 4.1 %	– 21.0 %
Finland	Mt CO_2-equivalent	71.0	70.9	78.3	70.8	78.4	75.7	71.0
	% from base year			10.3 %	– 0.3 %	10.4 %	6.5 %	0.0 %
France	Mt CO_2-equivalent	563.9	562.6	531.1	-	546.2	-	563.9
	% from base year			– 5.8 %	-	– 3.1 %	-	0.0 %
Germany	Mt CO_2-equivalent	1 232.4	1 215.2	956.1	944.3	981.9	969.3	973.6
	% from base year			– 22.4 %	– 23.4 %	– 20.3 %	– 21.3 %	– 21.0 %
Greece	Mt CO_2-equivalent	107.0	105.6	131.9	130.5	130.9	130.7	133.7
	% from base year			23.2 %	22.0 %	22.3 %	22.2 %	25.0 %
Ireland	Mt CO_2-equivalent	55.6	55.4	69.2	-	69.3	-	62.8
	% from base year			24.5 %	-	24.6 %	-	13.0 %
Italy	Mt CO_2-equivalent	516.9	516.3	552.8	540.7	566.7	560.8	483.3
	% from base year			6.9 %	4.6 %	9.7 %	8.5 %	– 6.5 %
Luxembourg	Mt CO_2-equivalent	13.2	13.1	12.9	12.4	12.9	13.1	9.5
	% from base year			– 1.9 %	– 5.9 %	– 1.8 %	– 0.8 %	– 28.0 %
Netherlands	Mt CO_2-equivalent	213.0	212.0	207.5	-	212.6	-	200.3
	% from base year			– 2.6 %	-	– 0.2 %	-	– 6.0 %
Portugal	Mt CO_2-equivalent	60.1	59.3	81.8	-	85.2	-	76.4
	% from base year			36.1 %	-	41.6 %	-	27.0 %
Spain	Mt CO_2-equivalent	289.8	288.1	442.3	-	430.6	-	333.2
	% from base year			52.6 %	-	48.6 %	-	15.0 %
Sweden	Mt CO_2-equivalent	72.2	71.9	65.4	-	67.9	-	75.0
	% from base year			– 9.3 %	-	– 5.9 %	-	4.0 %
United Kingdom	Mt CO_2-equivalent	776.3	771.1	636.7	-	651.3	-	679.3
	% from base year			– 18.0 %	-	– 16.1 %	-	– 12.5 %
EU-15 (a)	Mt CO_2-equivalent	4 265.5	4 232.9	4 052.0	4 001.1	4 134.0	4 098.2	3 924.3
	% from base year			– 5.0 %	– 6.2 %	– 3.1 %	– 3.9 %	– 8.0 %

Table 1: continued.

Country	Unit	Kyoto base-year	1990	2007	2008 ([b])	2003–2007 average	2004–2008 average ([b])	2008–2012 Kyoto target
Bulgaria	Mt CO_2-equivalent	132.6	117.7	75.8	-	72.3	-	122.0
	% from base year			- 42.8 %	-	- 45.5 %	-	- 8.0 %
Cyprus ([a])	Mt CO_2-equivalent	-	5.5	10.1	-	9.8	-	-
	% from 1990			85.3 %	-	-	-	-
Czech Republic	Mt CO_2-equivalent	194.2	194.7	150.8	-	147.8	-	178.7
	% from base year			- 22.4 %	-	- 23.9 %	-	- 8.0 %
Estonia	Mt CO_2-equivalent	42.6	41.9	22.0	-	20.2	-	39.2
	% from base year			- 48.3 %	-	- 52.6 %	-	- 8.0 %
Hungary	Mt CO_2-equivalent	115.4	99.2	75.9	-	79.3	-	108.5
	% from base year			- 34.2 %	-	- 31.3 %	-	- 6.0 %
Latvia	Mt CO_2-equivalent	25.9	26.7	12.1	-	11.4	-	23.8
	% from base year			- 53.4 %	-	- 56.1 %	-	- 8.0 %
Lithuania	Mt CO_2-equivalent	49.4	49.1	24.7	-	22.5	-	45.5
	% from base year			- 49.9 %	-	- 54.4 %	-	- 8.0 %
Malta ([a])	Mt CO_2-equivalent	-	2.0	3.0	-	2.9	-	-
	% from 1990			49.0 %	-	-	-	-
Poland	Mt CO_2-equivalent	563.4	459.5	398.9	-	390.5	-	529.6
	% from base year			- 29.2 %	-	- 30.7 %	-	- 6.0 %
Romania	Mt CO_2-equivalent	278.2	243.0	152.3	-	152.9	-	256.0
	% from base year			- 45.3 %	-	- 45.0 %	-	- 8.0 %
Slovak Republic	Mt CO_2-equivalent	72.1	73.3	47.0	-	49.1	-	66.3
	% from base year			- 34.8 %	-	- 31.9 %	-	- 8.0 %
Slovenia	Mt CO_2-equivalent	20.4	18.6	20.7	21.3	20.3	20.6	18.7
	% from base year			1.8 %	4.8 %	- 0.3 %	1.3 %	- 8.0 %
EU-27	Mt CO_2-equivalent	-	5 564.0	5 045.4	4 971.2	5 113.0	5 077.2	-
	% from 1990			- 9.3 %	- 10.7 %	-	-	-
Croatia	Mt CO_2-equivalent	36.0	31.4	32.4	-	30.7	-	34.2
	% from base year			- 10.1 %	-	- 14.9 %	-	- 5.0 %
Iceland	Mt CO_2-equivalent	3.4	3.4	4.5	-	4.0	-	3.7
	% from base year			34.9 %	-	18.2 %	-	10.0 %
Liechtenstein	Mt CO_2-equivalent	0.2	0.2	0.2	-	0.3	-	0.2
	% from base year			6.1 %	-	15.7 %	-	- 8.0 %
Norway	Mt CO_2-equivalent	49.6	49.7	55.1	53.8	54.2	54.1	50.1
	% from base year			10.9 %	8.4 %	9.2 %	9.1 %	1.0 %
Switzerland	Mt CO_2-equivalent	52.8	52.7	51.3	-	52.7	-	48.6
	% from base year			- 2.9 %	-	- 0.1 %	-	- 8.0 %
Turkey ([a])	Mt CO_2-equivalent	-	170.1	372.6	-	320.1	-	-
	% from 1990			119.1 %	-	-	-	-

Note: Emissions from international aviation and international maritime transport and emissions/removals from LULUCF are excluded.
([a]) Cyprus, Malta, the EU-27 and Turkey have no target under the Kyoto Protocol, and therefore no legal base year. In this table, 1990 emissions are taken as reference emissions for Cyprus, Malta, the EU-27 and Turkey.
([b]) Estimates of 2008 national emissions provided by Member States. 2008 emissions of the EU-15 and EU-27 estimated by EEA.

Source: EEA, 2009.

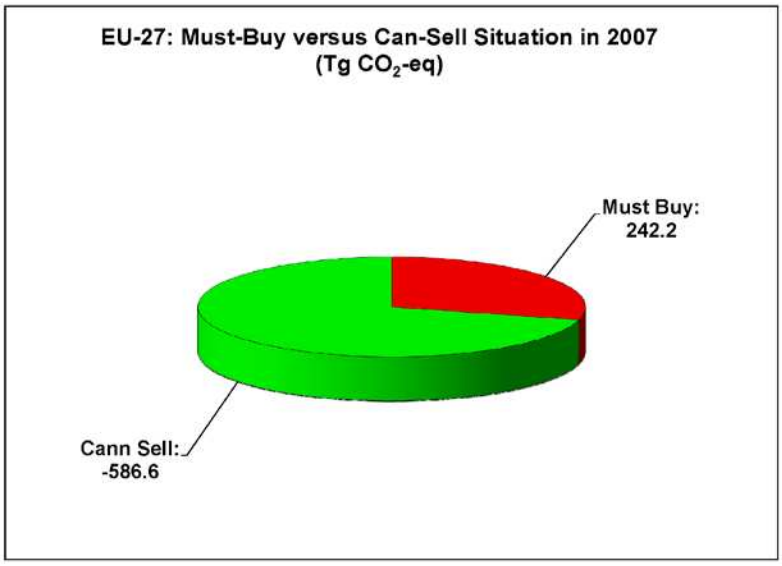

Figure 3: Figure 2 presented in absolute terms. Member States appearing as potential buyers in 2007: AT, DK, ES, FI, GR, IE, IT, LU, NL, PT, SI; Member States appearing as potential sellers in 2007: BE, BG, CZ, DE, EE, FR, HU, LT, LV, PL, RO, SE, SK, UK. Member States not considered: CY, MT. See ISO Country Code for country abbreviations.

Uncertainties are reported and extracted from the national inventory reports of the Member States. 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 EEA (2009a: Tab. 1.20 and 1.21) and is reproduced as Table 2 below. This compilation makes available quantified uncertainty estimates from the EU-27 Member States (extracted from their National Inventory Reports 2009 or earlier National Inventory Reports; cf. 2nd row in Tab. 2). The listed (CO_2 or combined) uncertainties refer to a confidence of 95% confidence interval[5] and exclude and/or include CO_2 emissions/removals due to land-use change and forestry (LUCF). Nine Member States – Belgium, Cyprus, Denmark, Finland, Germany, Malta, Poland, Slovakia and Slovenia – only report uncertainties that include LUCF emissions/removals.

Taking uncertainty into account in combination with undershooting is important because the amount by which a Member State undershoots its target or its 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.

Table 2: Uncertainty estimates available from EU-27 Member States excluding LUCF (with the exception of Belgium, Cyprus, Denmark, Finland, Germany, Malta, Poland, Slovakia and Slovenia) and Kyoto mechanisms.[6] Source: EEA (2009a: Tab. 1.20 and 1.21).

Member State	Austria		Belgium	Denmark	Finland	France	Germany	Greece	
Citation	NIR Mar 2009, pp.47-54		NIR Mar 2009, pp. 19-26	NIR Mar 2009 pp.51-54	NIR Mar 2009, pp. 30-32	NIR, March 2009, pp. 31-32	NIR Jan 2009 , pp. 95-97 + 564-572	NIR, March 2009, pp. 31-32	
Method used	Tier 1, Tier 2		Tier 1	Tier 1	Tier 1 + Tier 2	Tier 1	Tier 1	Tier 1	
Documentation in NIR (according to Table 6.1/6.2 of GPG)	Yes (Annex 6)		Yes (Annex 3)	Yes	Yes (Annex 5) Detailed uncertainty and sensitivity analyses performed for key categories.	Yes (Annex 7)	Yes: Annex 8	Yes (Annex IV)	
Years and sectors included	emissions: 2007; trends: 1990-2007; almost all categories (e. L.)		emissions: 2007; trends: 1990-2007; all categories, (i. L.)	emissions: 2007; trend BY-2007; almost all categories (i.L.)	emissions: 2007; trends: 1990-2007; all categories (i. L.)	emissions: 2006; trends: 1990-2006; all categories	emissions: 2007; trends: 1990-2007; all categories (i.L.)	emissions: 2007; trends: 1990-2007; almost all categories	
Uncertainty (%)	Tier 1	Tier 2	Tier 1	Tier 1	Tier 1	Tier 1	Tier 1	Tier 1 (i. L.)	Tier 1 (e. L.)
CO_2				3.1%				4.5%	3.6%
CH_4				23%				54.9%	55.9%
N_2O				47%				80.8%	81.0%
F-gases				48%				184%	184%
Total	4.0%	5.7%	7.6%	5.8%	22.6%	i. L.: 23% e. L.: 18.0%	9.7%	18.5%	7.4%
Uncertainty in trend (%)	Tier 1	Tier 2	Tier 1	Tier 1	Tier 1	Tier 1	Tier 1	Tier 1	Tier 1
CO_2				±2.4 % points					
CH_4				±10.3% points					
N_2O				±13% points					
F-gases				±66% points					
Total	2.1%	2.3%	2.8%	2.5% points	14.9% points	i. L.: 4.7% e. L.: 2.9%	12.97%	13.2%	9.0%

Table 2: continued.

Member State	Ireland	Italy	Luxembourg	Netherlands	Portugal	Spain	Sweden	United Kingdom	
Citation	NIR Mar 2009, pp. 17-23	NIR Apr 2009, pp. 35-36	MM submission 2009	NIR Mar 2009 p. 29-32	NIR Mar 2009, pp. 13-15	NIR Mar 2009, pp. 44-45	NIR Jan 2009, p.35-37	NIR Mar 2009, pp. 67-68, MM submission	
Method used	Tier 1	Tier 1	Tier 1	Tier 1	Tier 1	Tier 1	Tier 1	Tier 1, Tier 2	
Documentation in NIR (according to Table 6.1/6.2 of GPG)	Yes	Yes (Annex 1)	Yes (Tier 1 table)	Yes (Annex 7)	Yes (Annex B)	Yes (Annex 7)	Yes (Annex 7)	Yes (Annex 7)	
Years and sectors included	emissions: 2007; trend: 1990-2007; all categories (e.L.)	emissions: 2007; trend: BY-2007; all categories	emissions: 2007, trend: 1990-2007; allmost all categories (e.L.)	emissions: 2007; trend: 1990-2007; all categories (e.L.)	emissions and trends: BY-2007; all categories (i.L.)	emissions: 2006; trend: BY-2006; all categories (e. L.)	emissions: 1990 and 2007; trends: 1990-2007; almost all categories (e. L.)	emissions: 1990, 2007; trend: BY -2007, all categories	
Uncertainty (%)	Tier 1	Tier 1	Tier 1	Tier 1	Tier 1	Tier 1	Tier 1	Tier 1	Tier 2 (incl. LULUCF)
CO_2	1.2%			3%	5% (e.L.)	-	5.4% (1990) 5.4% (2007)		
CH_4	2.1%			25%	27.5% (e.L)	-	2.8% (1990) 1.9% (2007)		
N_2O	5.4%			50%	97.3% (e.L.)	-	5.3 % (1990) 5.1% (2007)		
F-gases	0.2%			50%	66.2%		0.2% (1990) 0.4% (2007)		
Total	6.0%	i. L.: 6.4% e. L.: 3.3%	3.1%	5%	8.7% (i.L.)	11.4%	8.0% (1990) 7.7% (2007)	i. L.: 15.8% e. L.: 15.7%	15% (1990) 13% (2007)
Uncertainty in trend (%)	Tier 1	Tier 1	Tier 1	Tier 1 (i. L.)	Tier 1	Tier 1	Tier 1	Tier 1	Tier 2
CO_2	1.8%			2 % points					
CH_4	2.0%			10 % points					
N_2O	2.8%			15 % points					
F-gases	0.2%			9 % points					
Total	3.8%	i. L.: 5.3% e. L.: 2.6%	2.6%	3 % points	13.2%	5.7%	6.4%	i. L.: 2.40%; e. L.: 2.43%	2.8%

Table 2: continued.

Member State	Bulgaria	Cyprus	Czech Republic	Estonia	Hungary	Latvia	Lithuania	Malta	Poland	Romania	Slovakia	Slovenia
Citation	NIR, March 2009, pp. 11-12	NIR, April 2009, pp. 11-12	NIR Mar 2009 pp. 23-27 + Uncertainty Table	NIR Mar 2009	NIR, March 2009, p. 24	NIR Apr 2009, p.23	NIR, Dec 2008, p. 19	NIR, March 2009, p. 14	NIR, March 2009, p. 14	NIR, March 2009, p. 42	NIR, March 2009, pp. 25-27	NIR Apr 2009, p. 20
Method used	Tier 1	Tier 1	Tier 1	Tier 1	Tier 1	Tier 1	Tier 1	Tier 1	Tier 1	Tier 1	Tier 1	Tier 1
Documentation in NIR (according to Table 6.1/6.2 of GPG)	Yes, Tier 1 table	Yes (Annex 2)	Yes	Yes (Annex 7)	Yes, Tier 1 table	Yes (Annex 7)	Yes: Annex 2	Yes: Annex 2	Yes (Annex 5)	Yes (Annex 7)	Yes (Annex 2)	Yes (Annex 7)
Years and sectors included	emissions: 2007; BY-2007; all categories (e. L.)	emissions: 1990-2007; trends: 1990-2007; most categories (i.L.)	emissions: 2007; trend: 1990- 2007; all categories (e. L.)	emissions: 1990; all categories	emissions: 2007; trend: BY-2007; all categories (e. L)	emissions: 2007; trend: 1990-2007; almost all categories	emissions: 2007; trends: BY-2007, allmost all categories (e. L)	emissions: 2007; trends: BY-2007, allmost all categories (i. L)	emissions: 2007 ; all sources	emissions: 2007; trend: 1989 to 2007; all categories	emissions 1990 and 2007; trend: 1990-2007; almost all categories	emissions: 1986, 2007; trend: 1986-2007; all categories
Uncertainty (%)	Tier 1	Tier 1 (2007)	Tier 1	Tier 1	Tier 1	Tier 1	Tier 1	Tier 1	Tier 1	Tier 1	Tier 1 (i. L)	Tier 1 (i. L)
CO_2					2-4%	3.6% (e.L.)	1.9%		3.3%			
CH_4					15-25%	16% (e.L)	2.7%		20.3%			
N_2O					80-90%	22% (e.L.)	7.7%		47.9%			
F-gases									HFC 44.7% PFC 20% SF6 100%			
Total	13.4%	8.4%	6.3%	i. L.: 21.2%; e. L.: 18.3%	5.1%	i. L.: 22.9%; e. L.: 5%	8.4%	3.8%		e. L.: 15.9% i. L.: 29.3%	2007: 14%	8.5% (1986) 7.3% (2007)
Uncertainty in trend (%)	Tier 1		Tier 1		Tier 1					Tier 1	Tier 1 (i. L)	Tier 1 (i. L)
CO_2						1.5%						
CH_4						7%						
N_2O						14%						
F-gases												
Total	4.1%	51.4%	3.1%	i. L.: 25.7%; e. L.: 8.6%	2.3%	i. L.: 13.1%; e. L.: 2.3%	2.2%	3.3%		e. L.: 5.6%; i. L.: 11.4%	8.0%	6.2%

2 Methodology

The applied Und&VT concept is described in detail in Jonas *et al.* (2004). With the help of δ_{KP}, the normalized emission change under 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 Eq. (32a,b) in Jonas *et al.*, 2004):

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

where ρ is assumed to be symmetrical and, in line with preparatory signal detection, constant over time, i.e., $\rho(t_1) = \rho(t_2)$ with t_1 referring to 1990 as base year[8] and t_2 to 2010 as commitment year (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: $\delta_{KP} > 0$	**Case 1**	$\delta_{crit} \leq \delta_{KP}$	Detectable EU/Kyoto target	
	Case 2	$\delta_{crit} > \delta_{KP}$	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: $\delta_{KP} \leq 0$	**Case 3**	$\delta_{crit} < \delta_{KP}$	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	$\delta_{crit} \geq \delta_{KP}$	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 agreed to emission reduction ($\delta_{KP} > 0$) and emission limitation ($\delta_{KP} \leq 0$) exhibit an over/undershooting dissimilarity (see Jonas *et al.*, 2004: Sections 3.1 and 3.2 for details).

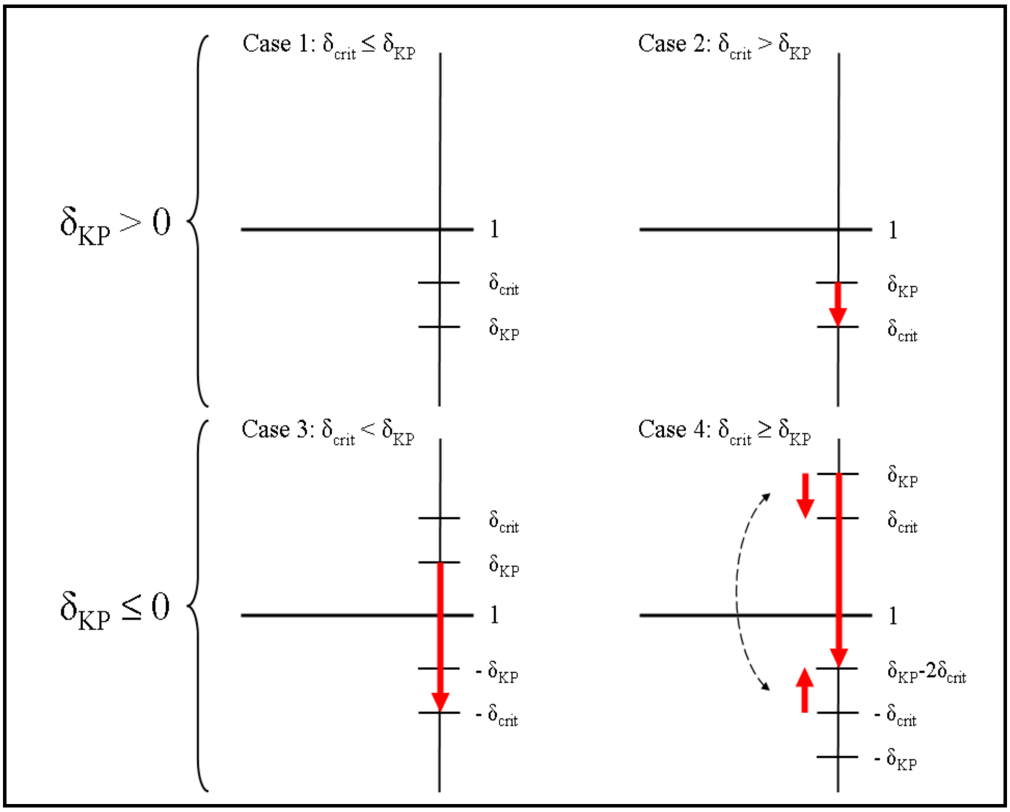

Figure 4: The four cases that are distinguished in applying the Und&VT concept (see also Table 3). Emission reduction: $\delta_{KP} > 0$; emission limitation: $\delta_{KP} \le 0$.

<u>*Case 1*</u>*:* $\delta_{KP} > 0 : \delta_{crit} \le \delta_{KP}$. Here, use is made of Eq. (43a), (B1), (D1), (B3) and (D2) of Jonas *et al*. (2004: Appendix D) (see also Jonas *et al*., 2010: SOM: Appendix D):

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

where

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

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

<u>*Case 2*</u>*:* $\delta_{KP} > 0 : \delta_{crit} > \delta_{KP}$. Here, use is made of equations (45a), (B1), (D3a,b), (D4) and (42b) of Jonas *et al*. (2004: Appendix D) (see also Jonas *et al*., 2010: SOM: Appendix D):

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

where

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

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

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 fall above its true emission limitation or reduction commitment (true emission target) Note: In Jonas *et al.* (2004: Section 3.4 and App. D) α is replaced by α_v in Cases 2–4 (with 'v' referring to 'verifiable'), which is not done here
δ_{KP}	A Member State's normalized emission change agreed under 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.* (2004: Section 3.4 and App. D) U is replaced by U_v in Cases 2–4 (with 'v' referring to 'verifiable'), 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 'detectability reference' 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 The said risk α (e.g., the $x_{t,2}$-greater-than-$(1-\delta_{KP})x_{t,i}$ risk in Case 1) can be grasped and quantified although true emissions are unknown by definition (but not necessarily their ratios)

<u>Case 3</u>: $\delta_{KP} \le 0 : \delta_{crit} < \delta_{KP}$. Here, use is made of equations (50a), (B1), (D7a,b), (D8) and (52) of Jonas *et al.* (2004: Appendix D) (see also Jonas *et al.*, 2010: SOM: Appendix D):[9]

$$\frac{x_1}{x_2} \le (1+\delta_{crit})\frac{1}{1+(1-2\alpha)\rho} = 1-\delta_{\text{mod}} \ , \qquad (11), (3)$$

where

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

$$U = U_{gap} + (1+\delta_{crit})\frac{(1-2\alpha)\rho}{1+(1-2\alpha)\rho}. \qquad (13)$$

with

$$U_{gap} = -(\delta_{crit} + \delta_{KP}) \, . \qquad (14)$$

<u>Case 4</u>: $\delta_{KP} \le 0 : \delta_{crit} \ge \delta_{KP}$. Here, use is made of equations (55a), (B1), (D11a,b), (D12), (57) and (58) of Jonas *et al*. (2004: Appendix D) (see also Jonas *et al*., 2010: SOM: Appendix D):[9]

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

where

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

$$U = U_{gap} + (1+\delta'_{crit})\frac{(1-2\alpha)\rho}{1+(1-2\alpha)\rho}. \qquad (17)$$

with

$$U_{gap} = -2\delta_{crit} \qquad (18)$$

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

The inversions $\rho = \rho\left(\delta_{KP}, U, \alpha\right)$ of Eq. (6), (9), (13) and (17) are given in the Appendix. They are used to determine the uncertainty for a given undershooting (typically for U equal to DTPI, here with reference to 2008/12) and in dependence of δ_{KP} and α.

It is recalled that emission reductions are measured positively ($\delta_{KP} > 0$) and emission increases negatively ($\delta_{KP} < 0$), 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), Eq. (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 EU burden sharing in compliance with the Kyoto Protocol (see Table 1), allows identifying which case applies to which Member State, that is, the conditions that underlie the emissions reporting of a particular Member State and the EU-27 as a whole (see Tables 3 and 6).

Table 7 lists the Member States' modified emission limitation or reduction targets δ_{mod} (Eq. (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. Table 8 lists the undershooting U (Eq. (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 Eq. (5)) that matters initially because it describes a Member State's overall burden. However, once Member States have agreed on δ_{KP} targets, it is the undershooting U which then becomes important. Therefore, only U is considered in the second step of the evaluation where the focus is on the Member States' emissions as of 2007.

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}) derived with the help of Eq. (1) for a range of relative uncertainty values (ρ), covering the uncertainty estimates of the EU-27 Member States (cf. Table 2).

	$\delta_{KP}>0$	$\delta_{KP}\le 0$		$\delta_{KP}>0$	$\delta_{KP}\le 0$
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			

In the second step, the U values reported in Table 8 are multiplied with the factor $(-17/20)$. 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 $(-17/20)$ establishes the linear path (base year–commitment year) emission targets and undershooting opportunities for the year 2007 (see Tab. 9).

Table 6: The conditions (in the form of Cases 1–4) that underlie the emissions reporting of a particular EU-27 Member State (MS) and the EU-15 as a whole (which has approved, as a Party, the Kyoto Protocol to the United Nations Framework on Climate Change). 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). Blue: Member States having no Kyoto target.

MS	δ_{KP} %	Case Identification for ρ =								
		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
BG	8.0	Case 1	Case 1	Case 1	Case 1	Case 2	Case 2	Case 2	Case 2	Case 2
CY	-									
CZ	8.0	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
EE	8.0	Case 1	Case 1	Case 1	Case 1	Case 2	Case 2	Case 2	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
HU	6%	Case 1	Case 1	Case 1	Case 2	Case 2	Case 2	Case 2	Case 2	Case 2
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
LV	8.0	Case 1	Case 1	Case 1	Case 1	Case 2	Case 2	Case 2	Case 2	Case 2
LT	8.0	Case 1	Case 1	Case 1	Case 1	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
MT	-									
NL	6.0	Case 1	Case 1	Case 1	Case 2	Case 2	Case 2	Case 2	Case 2	Case 2
PL	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
RO	8.0	Case 1	Case 1	Case 1	Case 1	Case 2	Case 2	Case 2	Case 2	Case 2
SK	8.0	Case 1	Case 1	Case 1	Case 1	Case 2	Case 2	Case 2	Case 2	Case 2
SI	8.0	Case 1	Case 1	Case 1	Case 1	Case 2	Case 2	Case 2	Case 2	Case 2
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-27 Member States (MS) and the EU-15 as a whole. The table lists the 2008–2012 modified emission limitation or reduction targets δ_{mod} (i.e., Eq. (5) applied in combination with Table 8), 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
BG	**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
CZ	**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
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
EE	**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
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

Table 7: continued.

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
HU	**6,0**	0,0	6,0	8,3	10,5	-17,5	-13,6	-6,6	-0,4	9,8	18,0
		0,1	6,0	7,8	9,6	-18,8	-15,2	-8,6	-2,8	7,0	14,9
		0,2	6,0	7,4	8,7	-20,0	-16,8	-10,8	-5,4	3,8	11,4
		0,3	6,0	6,9	7,8	-21,3	-18,4	-13,0	-8,2	0,3	7,4
		0,4	6,0	6,5	6,9	-22,6	-20,1	-15,4	-11,1	-3,6	2,9
		0,5	6,0	6,0	6,0	-24,0	-21,9	-18,0	-14,3	-7,9	-2,4
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
LV	**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
LT	**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
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

Table 7: continued.

PL	**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	-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
RO	**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
SK	**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
SI	**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
ES	**-15**	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-27 Member States (MS) and the EU-15 as a whole. The table lists the undershooting U (Eq. (6), (9), (13) and (17)) contained in the modified emission limitation or reduction targets δ_{mod} listed in Table 7.

MS	δ_{KP}	α	Undershooting U in % for $\rho =$								
	%	1	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
BG	**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
CZ	**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
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
EE	**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
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

Table 8: continued.

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
HU	**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
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
LV	**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
LT	**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
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

Table 8: continued.

PL	**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
RO	**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
SK	**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
SI	**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
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 (as well as the Member States' agreed δ_{KP} values) listed in Table 8 multiplied with the factor $(-17/20)$ to reconcile the Und&VT concept with the emissions reporting for the EU and to establish the linear path emissions targets and undershooting opportunities for 2007.

MS	δ_{KP_07}	α	**Undershooting U in % for** $\rho =$								
	%	**1**	**0%**	**2.5%**	**5%**	**7.5%**	**10%**	**15%**	**20%**	**30%**	**40%**
AT	**-11.1**	0.0	0.0	-1.8	-3.5	-5.2	-6.7	-9.7	-14.9	-23.7	-30.6
		0.1	0.0	-1.5	-2.8	-4.2	-5.5	-8.0	-12.9	-21.2	-28.0
		0.2	0.0	-1.1	-2.2	-3.2	-4.2	-6.1	-10.7	-18.5	-25.0
		0.3	0.0	-0.7	-1.5	-2.2	-2.8	-4.2	-8.4	-15.6	-21.6
		0.4	0.0	-0.4	-0.7	-1.1	-1.5	-2.2	-5.8	-12.3	-17.7
		0.5	0.0	0.0	0.0	0.0	0.0	0.0	-3.1	-8.6	-13.2
BE	**-6.4**	0.0	0.0	-1.9	-3.7	-5.5	-8.4	-14.4	-19.6	-28.3	-35.3
		0.1	0.0	-1.5	-3.0	-4.5	-7.1	-12.6	-17.6	-25.9	-32.6
		0.2	0.0	-1.2	-2.3	-3.4	-5.7	-10.8	-15.4	-23.2	-29.7
		0.3	0.0	-0.8	-1.5	-2.3	-4.3	-8.9	-13.0	-20.2	-26.3
		0.4	0.0	-0.4	-0.8	-1.2	-2.9	-6.9	-10.5	-16.9	-22.4
		0.5	0.0	0.0	0.0	0.0	-1.4	-4.7	-7.8	-13.2	-17.9
BG	**-6.8**	0.0	0.0	-1.9	-3.7	-5.5	-8.0	-13.9	-19.2	-27.9	-34.8
		0.1	0.0	-1.5	-3.0	-4.4	-6.7	-12.2	-17.1	-25.5	-32.2
		0.2	0.0	-1.2	-2.3	-3.4	-5.3	-10.4	-15.0	-22.8	-29.2
		0.3	0.0	-0.8	-1.5	-2.3	-3.9	-8.5	-12.6	-19.8	-25.9
		0.4	0.0	-0.4	-0.8	-1.2	-2.4	-6.4	-10.1	-16.5	-22.0
		0.5	0.0	0.0	0.0	0.0	-0.9	-4.3	-7.4	-12.8	-17.5
CZ	**-6.8**	0.0	0.0	-1.9	-3.7	-5.5	-8.0	-13.9	-19.2	-27.9	-34.8
		0.1	0.0	-1.5	-3.0	-4.4	-6.7	-12.2	-17.1	-25.5	-32.2
		0.2	0.0	-1.2	-2.3	-3.4	-5.3	-10.4	-15.0	-22.8	-29.2
		0.3	0.0	-0.8	-1.5	-2.3	-3.9	-8.5	-12.6	-19.8	-25.9
		0.4	0.0	-0.4	-0.8	-1.2	-2.4	-6.4	-10.1	-16.5	-22.0
		0.5	0.0	0.0	0.0	0.0	-0.9	-4.3	-7.4	-12.8	-17.5
DK	**-17.9**	0.0	0.0	-1.6	-3.2	-4.7	-6.1	-8.8	-11.2	-16.9	-23.8
		0.1	0.0	-1.3	-2.6	-3.8	-5.0	-7.2	-9.3	-14.4	-21.2
		0.2	0.0	-1.0	-2.0	-2.9	-3.8	-5.5	-7.2	-11.7	-18.2
		0.3	0.0	-0.7	-1.3	-2.0	-2.6	-3.8	-5.0	-8.8	-14.8
		0.4	0.0	-0.3	-0.7	-1.0	-1.3	-2.0	-2.6	-5.5	-10.9
		0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.8	-6.4
EE	**-6.8**	0.0	0.0	-1.9	-3.7	-5.5	-8.0	-13.9	-19.2	-27.9	-34.8
		0.1	0.0	-1.5	-3.0	-4.4	-6.7	-12.2	-17.1	-25.5	-32.2
		0.2	0.0	-1.2	-2.3	-3.4	-5.3	-10.4	-15.0	-22.8	-29.2
		0.3	0.0	-0.8	-1.5	-2.3	-3.9	-8.5	-12.6	-19.8	-25.9
		0.4	0.0	-0.4	-0.8	-1.2	-2.4	-6.4	-10.1	-16.5	-22.0
		0.5	0.0	0.0	0.0	0.0	-0.9	-4.3	-7.4	-12.8	-17.5
FI	**0.0**	0.0	0.0	-4.2	-8.3	-12.3	-16.3	-24.1	-31.9	-47.6	-64.8
		0.1	0.0	-3.8	-7.6	-11.3	-15.0	-22.5	-30.0	-45.8	-63.5
		0.2	0.0	-3.4	-6.8	-10.3	-13.7	-20.8	-28.1	-43.8	-62.2
		0.3	0.0	-3.0	-6.1	-9.2	-12.4	-19.0	-26.0	-41.6	-60.6
		0.4	0.0	-2.6	-5.3	-8.0	-10.9	-17.0	-23.7	-39.2	-58.8
		0.5	0.0	-2.2	-4.5	-6.9	-9.4	-15.0	-21.3	-36.4	-56.7
FR	**0.0**	0.0	0.0	-4.2	-8.3	-12.3	-16.3	-24.1	-31.9	-47.6	-64.8
		0.1	0.0	-3.8	-7.6	-11.3	-15.0	-22.5	-30.0	-45.8	-63.5
		0.2	0.0	-3.4	-6.8	-10.3	-13.7	-20.8	-28.1	-43.8	-62.2
		0.3	0.0	-3.0	-6.1	-9.2	-12.4	-19.0	-26.0	-41.6	-60.6
		0.4	0.0	-2.6	-5.3	-8.0	-10.9	-17.0	-23.7	-39.2	-58.8
		0.5	0.0	-2.2	-4.5	-6.9	-9.4	-15.0	-21.3	-36.4	-56.7

Table 9: continued.

DE	**-17.9**	0.0	0.0	-1.6	-3.2	-4.7	-6.1	-8.8	-11.2	-16.9	-23.8
		0.1	0.0	-1.3	-2.6	-3.8	-5.0	-7.2	-9.3	-14.4	-21.2
		0.2	0.0	-1.0	-2.0	-2.9	-3.8	-5.5	-7.2	-11.7	-18.2
		0.3	0.0	-0.7	-1.3	-2.0	-2.6	-3.8	-5.0	-8.8	-14.8
		0.4	0.0	-0.3	-0.7	-1.0	-1.3	-2.0	-2.6	-5.5	-10.9
		0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.8	-6.4
GR	**21.3**	0.0	0.0	-6.8	-13.6	-20.2	-26.8	-39.9	-53.1	-68.9	-86.0
		0.1	0.0	-6.4	-12.7	-19.0	-25.4	-38.2	-51.3	-67.1	-84.8
		0.2	0.0	-5.9	-11.8	-17.8	-23.8	-36.3	-49.3	-65.1	-83.4
		0.3	0.0	-5.4	-10.9	-16.5	-22.2	-34.3	-47.2	-62.9	-81.8
		0.4	0.0	-4.9	-9.9	-15.2	-20.6	-32.2	-45.0	-60.4	-80.0
		0.5	0.0	-4.4	-8.9	-13.8	-18.9	-30.0	-42.5	-57.7	-77.9
HU	**-5.1**	0.0	0.0	-1.9	-3.8	-6.3	-9.7	-15.6	-20.9	-29.6	-36.5
		0.1	0.0	-1.6	-3.1	-5.3	-8.4	-13.9	-18.8	-27.2	-33.9
		0.2	0.0	-1.2	-2.3	-4.2	-7.0	-12.1	-16.7	-24.5	-30.9
		0.3	0.0	-0.8	-1.6	-3.1	-5.6	-10.2	-14.3	-21.5	-27.6
		0.4	0.0	-0.4	-0.8	-2.0	-4.1	-8.1	-11.8	-18.2	-23.7
		0.5	0.0	0.0	0.0	-0.8	-2.6	-6.0	-9.1	-14.5	-19.2
IE	**11.1**	0.0	0.0	-6.6	-13.1	-19.5	-25.9	-35.2	-42.9	-58.7	-75.8
		0.1	0.0	-6.2	-12.3	-18.4	-24.6	-33.6	-41.1	-56.9	-74.6
		0.2	0.0	-5.7	-11.5	-17.3	-23.3	-31.8	-39.1	-54.9	-73.2
		0.3	0.0	-5.3	-10.7	-16.2	-21.9	-30.0	-37.0	-52.7	-71.6
		0.4	0.0	-4.8	-9.8	-15.0	-20.4	-28.1	-34.8	-50.2	-69.8
		0.5	0.0	-4.4	-8.9	-13.8	-18.9	-26.1	-32.3	-47.5	-67.7
IT	**-5.5**	0.0	0.0	-1.9	-3.8	-5.9	-9.2	-15.2	-20.4	-29.2	-36.1
		0.1	0.0	-1.6	-3.1	-4.9	-7.9	-13.5	-18.4	-26.7	-33.5
		0.2	0.0	-1.2	-2.3	-3.8	-6.6	-11.7	-16.2	-24.1	-30.5
		0.3	0.0	-0.8	-1.6	-2.7	-5.2	-9.7	-13.9	-21.1	-27.1
		0.4	0.0	-0.4	-0.8	-1.6	-3.7	-7.7	-11.4	-17.8	-23.3
		0.5	0.0	0.0	0.0	-0.4	-2.2	-5.6	-8.6	-14.1	-18.8
LV	**-6.8**	0.0	0.0	-1.9	-3.7	-5.5	-8.0	-13.9	-19.2	-27.9	-34.8
		0.1	0.0	-1.5	-3.0	-4.4	-6.7	-12.2	-17.1	-25.5	-32.2
		0.2	0.0	-1.2	-2.3	-3.4	-5.3	-10.4	-15.0	-22.8	-29.2
		0.3	0.0	-0.8	-1.5	-2.3	-3.9	-8.5	-12.6	-19.8	-25.9
		0.4	0.0	-0.4	-0.8	-1.2	-2.4	-6.4	-10.1	-16.5	-22.0
		0.5	0.0	0.0	0.0	0.0	-0.9	-4.3	-7.4	-12.8	-17.5
LT	**-6.8**	0.0	0.0	-1.9	-3.7	-5.5	-8.0	-13.9	-19.2	-27.9	-34.8
		0.1	0.0	-1.5	-3.0	-4.4	-6.7	-12.2	-17.1	-25.5	-32.2
		0.2	0.0	-1.2	-2.3	-3.4	-5.3	-10.4	-15.0	-22.8	-29.2
		0.3	0.0	-0.8	-1.5	-2.3	-3.9	-8.5	-12.6	-19.8	-25.9
		0.4	0.0	-0.4	-0.8	-1.2	-2.4	-6.4	-10.1	-16.5	-22.0
		0.5	0.0	0.0	0.0	0.0	-0.9	-4.3	-7.4	-12.8	-17.5
LU	**-23.8**	0.0	0.0	-1.5	-2.9	-4.3	-5.6	-8.0	-10.2	-14.1	-17.8
		0.1	0.0	-1.2	-2.4	-3.5	-4.5	-6.6	-8.4	-11.8	-15.2
		0.2	0.0	-0.9	-1.8	-2.6	-3.5	-5.1	-6.6	-9.3	-12.2
		0.3	0.0	-0.6	-1.2	-1.8	-2.4	-3.5	-4.5	-6.6	-8.9
		0.4	0.0	-0.3	-0.6	-0.9	-1.2	-1.8	-2.4	-3.5	-5.0
		0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.5
NL	**-5.1**	0.0	0.0	-1.9	-3.8	-6.3	-9.7	-15.6	-20.9	-29.6	-36.5
		0.1	0.0	-1.6	-3.1	-5.3	-8.4	-13.9	-18.8	-27.2	-33.9
		0.2	0.0	-1.2	-2.3	-4.2	-7.0	-12.1	-16.7	-24.5	-30.9
		0.3	0.0	-0.8	-1.6	-3.1	-5.6	-10.2	-14.3	-21.5	-27.6
		0.4	0.0	-0.4	-0.8	-2.0	-4.1	-8.1	-11.8	-18.2	-23.7
		0.5	0.0	0.0	0.0	-0.8	-2.6	-6.0	-9.1	-14.5	-19.2

Table 9: continued.

PL	**-5.1**	0.0	0.0	-1.9	-3.8	-6.3	-9.7	-15.6	-20.9	-29.6	-36.5
		0.1	0.0	-1.6	-3.1	-5.3	-8.4	-13.9	-18.8	-27.2	-33.9
		0.2	0.0	-1.2	-2.3	-4.2	-7.0	-12.1	-16.7	-24.5	-30.9
		0.3	0.0	-0.8	-1.6	-3.1	-5.6	-10.2	-14.3	-21.5	-27.6
		0.4	0.0	-0.4	-0.8	-2.0	-4.1	-8.1	-11.8	-18.2	-23.7
		0.5	0.0	0.0	0.0	-0.8	-2.6	-6.0	-9.1	-14.5	-19.2
PT	**23.0**	0.0	0.0	-6.9	-13.7	-20.4	-27.0	-40.2	-53.4	-70.6	-87.7
		0.1	0.0	-6.4	-12.8	-19.1	-25.5	-38.4	-51.5	-68.8	-86.5
		0.2	0.0	-5.9	-11.8	-17.8	-23.9	-36.4	-49.5	-66.8	-85.1
		0.3	0.0	-5.4	-10.9	-16.5	-22.3	-34.4	-47.3	-64.6	-83.5
		0.4	0.0	-4.9	-9.9	-15.2	-20.6	-32.3	-45.0	-62.1	-81.7
		0.5	0.0	-4.4	-8.9	-13.8	-18.9	-30.0	-42.5	-59.4	-79.6
RO	**-6.8**	0.0	0.0	-1.9	-3.7	-5.5	-8.0	-13.9	-19.2	-27.9	-34.8
		0.1	0.0	-1.5	-3.0	-4.4	-6.7	-12.2	-17.1	-25.5	-32.2
		0.2	0.0	-1.2	-2.3	-3.4	-5.3	-10.4	-15.0	-22.8	-29.2
		0.3	0.0	-0.8	-1.5	-2.3	-3.9	-8.5	-12.6	-19.8	-25.9
		0.4	0.0	-0.4	-0.8	-1.2	-2.4	-6.4	-10.1	-16.5	-22.0
		0.5	0.0	0.0	0.0	0.0	-0.9	-4.3	-7.4	-12.8	-17.5
SK	**-6.8**	0.0	0.0	-1.9	-3.7	-5.5	-8.0	-13.9	-19.2	-27.9	-34.8
		0.1	0.0	-1.5	-3.0	-4.4	-6.7	-12.2	-17.1	-25.5	-32.2
		0.2	0.0	-1.2	-2.3	-3.4	-5.3	-10.4	-15.0	-22.8	-29.2
		0.3	0.0	-0.8	-1.5	-2.3	-3.9	-8.5	-12.6	-19.8	-25.9
		0.4	0.0	-0.4	-0.8	-1.2	-2.4	-6.4	-10.1	-16.5	-22.0
		0.5	0.0	0.0	0.0	0.0	-0.9	-4.3	-7.4	-12.8	-17.5
SI	**-6.8**	0.0	0.0	-1.9	-3.7	-5.5	-8.0	-13.9	-19.2	-27.9	-34.8
		0.1	0.0	-1.5	-3.0	-4.4	-6.7	-12.2	-17.1	-25.5	-32.2
		0.2	0.0	-1.2	-2.3	-3.4	-5.3	-10.4	-15.0	-22.8	-29.2
		0.3	0.0	-0.8	-1.5	-2.3	-3.9	-8.5	-12.6	-19.8	-25.9
		0.4	0.0	-0.4	-0.8	-1.2	-2.4	-6.4	-10.1	-16.5	-22.0
		0.5	0.0	0.0	0.0	0.0	-0.9	-4.3	-7.4	-12.8	-17.5
ES	**12.8**	0.0	0.0	-6.6	-13.2	-19.6	-26.1	-36.9	-44.6	-60.4	-77.5
		0.1	0.0	-6.2	-12.4	-18.5	-24.7	-35.3	-42.8	-58.6	-76.3
		0.2	0.0	-5.7	-11.5	-17.4	-23.4	-33.5	-40.8	-56.6	-74.9
		0.3	0.0	-5.3	-10.7	-16.2	-21.9	-31.7	-38.7	-54.4	-73.3
		0.4	0.0	-4.8	-9.8	-15.0	-20.4	-29.8	-36.5	-51.9	-71.5
		0.5	0.0	-4.4	-8.9	-13.8	-18.9	-27.8	-34.0	-49.2	-69.4
SE	**3.4**	0.0	0.0	-6.4	-11.7	-15.7	-19.7	-27.5	-35.3	-51.0	-68.2
		0.1	0.0	-6.0	-11.0	-14.7	-18.4	-25.9	-33.4	-49.2	-66.9
		0.2	0.0	-5.6	-10.2	-13.7	-17.1	-24.2	-31.5	-47.2	-65.6
		0.3	0.0	-5.2	-9.5	-12.6	-15.8	-22.4	-29.4	-45.0	-64.0
		0.4	0.0	-4.8	-8.7	-11.4	-14.3	-20.4	-27.1	-42.6	-62.2
		0.5	0.0	-4.4	-7.9	-10.3	-12.8	-18.4	-24.7	-39.8	-60.1
UK	**-10.6**	0.0	0.0	-1.8	-3.5	-5.2	-6.8	-10.1	-15.3	-24.1	-31.0
		0.1	0.0	-1.5	-2.9	-4.2	-5.5	-8.4	-13.3	-21.6	-28.4
		0.2	0.0	-1.1	-2.2	-3.2	-4.2	-6.6	-11.1	-19.0	-25.4
		0.3	0.0	-0.7	-1.5	-2.2	-2.9	-4.6	-8.8	-16.0	-22.0
		0.4	0.0	-0.4	-0.7	-1.1	-1.5	-2.6	-6.3	-12.7	-18.2
		0.5	0.0	0.0	0.0	0.0	0.0	-0.5	-3.5	-9.0	-13.7
EU-15	**-6.8**	0.0	0.0	-1.9	-3.7	-5.5	-8.0	-13.9	-19.2	-27.9	-34.8
		0.1	0.0	-1.5	-3.0	-4.4	-6.7	-12.2	-17.1	-25.5	-32.2
		0.2	0.0	-1.2	-2.3	-3.4	-5.3	-10.4	-15.0	-22.8	-29.2
		0.3	0.0	-0.8	-1.5	-2.3	-3.9	-8.5	-12.6	-19.8	-25.9
		0.4	0.0	-0.4	-0.8	-1.2	-2.4	-6.4	-10.1	-16.5	-22.0
		0.5	0.0	0.0	0.0	0.0	-0.9	-4.3	-7.4	-12.8	-17.5

4 Interpretation of Results and Conclusions

To interpret the results for 2007, 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 0.5, 0.4, …, 0.

(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) 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 DTPIs displayed in Figure 2 are always shown to contrast the Member States' linear path emission targets and undershooting options and challenges for the year 2007 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: Eq. (6)) or $U_{Gap} > 0$ (Cases 2–4: Eq. (9), (13) and (17) in which U_{Gap} is > 0 because Eq. (9), (13) and (17) have not yet been multiplied with the factor ($-17/20$)). 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} (Eq. (10), (14) and (18)) and thus of ρ (Eq. (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 14 countries that exhibit a negative DTPI: BE, BG, CZ, DE, EE, FR, HU, LT, LV, PL, RO, SE, SK and the UK (cf. Fig. 2). Given $\alpha = 0.5$, LV, LT, EE, RO, BG, SK, HU and PL are the best potential sellers followed by DE, the CZ, the UK, BE, SE and FR (Fig. 5). LV, LT, EE, RO, BG, SK, HU and PL can report with a relative uncertainty > 40% and still exhibit a detectable signal (see Tab. A1 for exact numbers); while DE, the CZ and the UK must report within the 20–40% relative uncertainty class (more exactly: up to 36%, 36% and 27%, respectively), BE within the 10–20% relative uncertainty class (more exactly: up to 13%), and SE and FR within the 5–10% relative uncertainty class (more exactly: up to 10% and 6%).

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), LV, LT, EE, RO and BG can still report with a relative uncertainty > 40% (see Table A1 for exact numbers); while SK, HU and PL must report within the 20–40% relative uncertainty class (more exactly: up to 30%, 29% and 23%, respectively); the CZ and the UK within the 10–20% relative uncertainty class (more exactly: up to 16% and 11%, respectively); DE and SE within the 5–10% relative uncertainty class (more exactly: up to 7% and 6%, respectively); and both BE and FR within the 0–5% relative uncertainty class (more exactly: up to 4.7 and 3.5%, respectively).

(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 $(-17/20)$ is disregarded) appears only for Member States that agreed to emission limitation (ES, FI, FR, GR, IE, PT and SE; see Tab. 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 (Fig. 12–14), an increasing number of Member States that agreed to emission reduction also exhibit a $U_{Gap} < 0$, for $\rho = 40\%$ eventually all of them (Fig. 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; Fig. 5–10) is preferred over interpretation II (U by α with ρ as a parameter; Fig. 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 DTPI meets U_{Gap} for a given ρ. (The UK, e.g., meets U_{Gap} for $\rho = 20\%$ but not any more for $\rho = 40\%$; Fig. 13 and 14.)

The following four conclusions emerge from this study:

(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 analysis techniques to the Annex B countries under the Kyoto Protocol. An in-depth quantitative comparison of the four, plus two additional, preparatory signal analysis techniques has been prepared by Jonas *et al.* (2010). The frame of reference for preparatory signal detection is that Annex B countries comply with their agreed emission targets in 2008–2012. By contrast, in this study one of these techniques, the Und&VT concept, is applied to the old and new Member States of the European Union under EU burden sharing in compliance with the Kyoto Protocol, but with reference to the linear path (base year–commitment year) emission targets as of 2007. The exercise shows that 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 DTPI, 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 (true emission target); and (ii) the detectability of the Member State's agreed emission 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 2007, fourteen EU-27 Member States exhibit a negative DTPI and thus appear as potential sellers: BE, BG, CZ, DE, EE, FR, HU, LT, LV, PL, RO, SE, SK, and the UK (Fig. 2). However, expecting that all of the EU Member States will eventually exhibit relative uncertainties in the range of 5–10% and above rather than below excluding LUCF and Kyoto mechanisms (cf. Tab. 2: quantified uncertainty estimates are available from all EU-27 Member States), 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 fall above their true emission targets. These conditions are met differently: Potential low-risk sellers (Figure 9: ranked in terms of credibility) are LV, LT, EE, RO and BG which can report with a relative uncertainty > 40% and still exhibit a detectable signal; while SK, HU and PL, and the CZ and the UK can still report within the 20–40% and 10–20% relative uncertainty class, respectively. In contrast, DE, BE, SE and FR can only act as potential sellers with a higher risk: DE, BE and SE only with $\alpha \approx 0.1$, $\alpha \approx 0.3$ and $\alpha \approx 0.4$, respectively, within the upper part of the 5–10% relative uncertainty class (Figures 6, 7, 9); and FR only with $\alpha = 0.5$ but in the 0–5% relative uncertainty class (Fig. 5). The other EU-27 Member States exhibit positive DTPIs, i.e., they do not meet their linear path (base year–commitment year) emission targets as of 2007, or do not have Kyoto targets at all (CY and MT).

(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 agreed 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 (i.e., increasingly negative) to achieve detectability. That is, for $\rho = 5\%$ only the Member States which agreed 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 (Fig. 11). For $\rho = 10\%$ BE, IT, the NL, SI as well as the EU-15 also require a $U_{Gap} < 0$ (Fig. 12 with the focus on Member States with $U_{Gap} < \mathrm{DTPI}$), indicating that somewhere within the 5–10% relative uncertainty range non-detectability will become a problem also for these Member States. 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: Eq. 6); these are, in absolute terms and with reference to 2010, 8.1% (BE), 7.0% (IT), 6.4% (NL) and 8.7% (SI and EU-15), respectively, assuming that the emission limitation or reduction targets are met under 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.

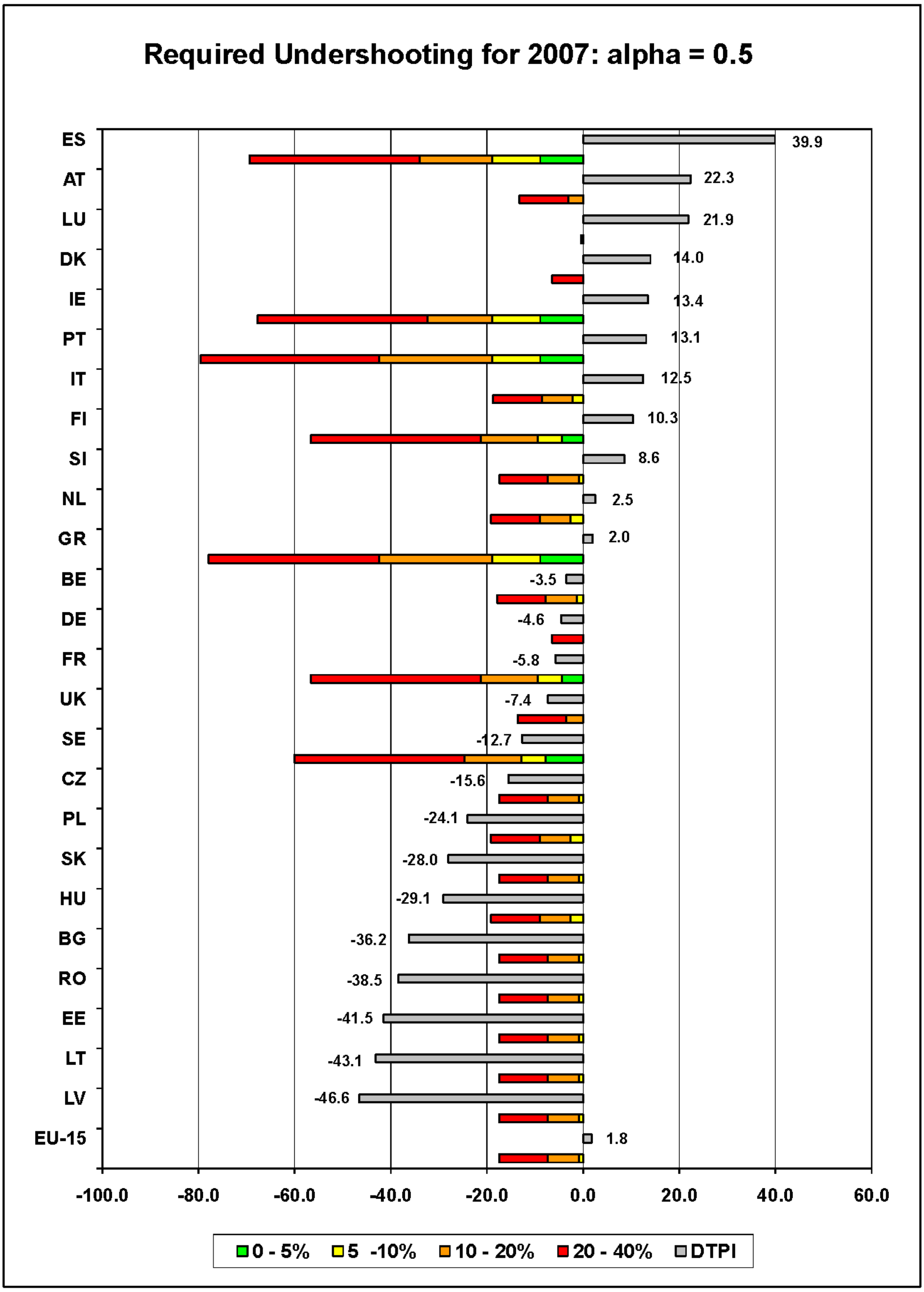

Figure 5: U by ρ (see intervals) for $\alpha = 0.5$ in addition to the DTPI.

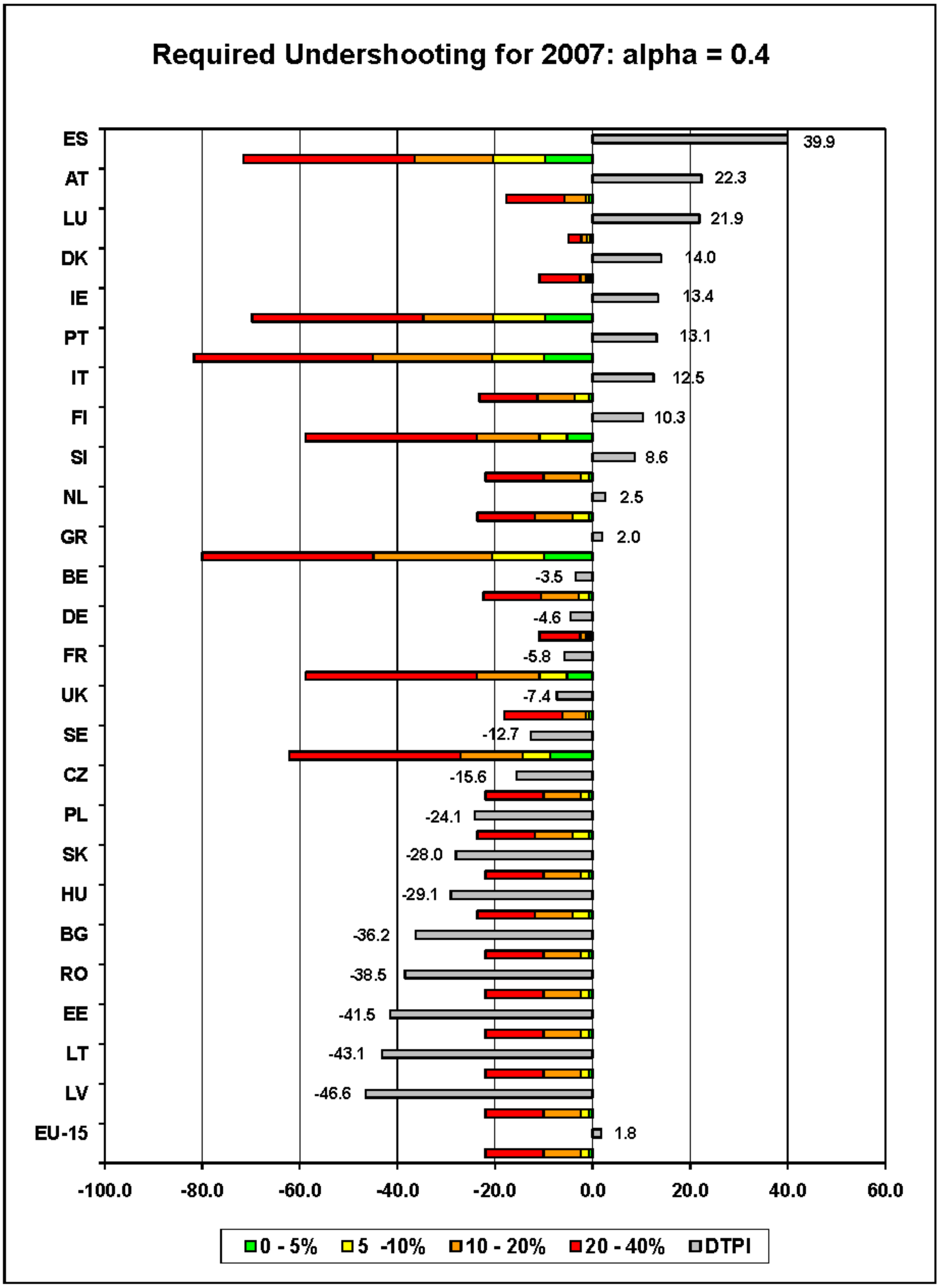

Figure 6: U by ρ (see intervals) for $\alpha = 0.4$ in addition to the DTPI.

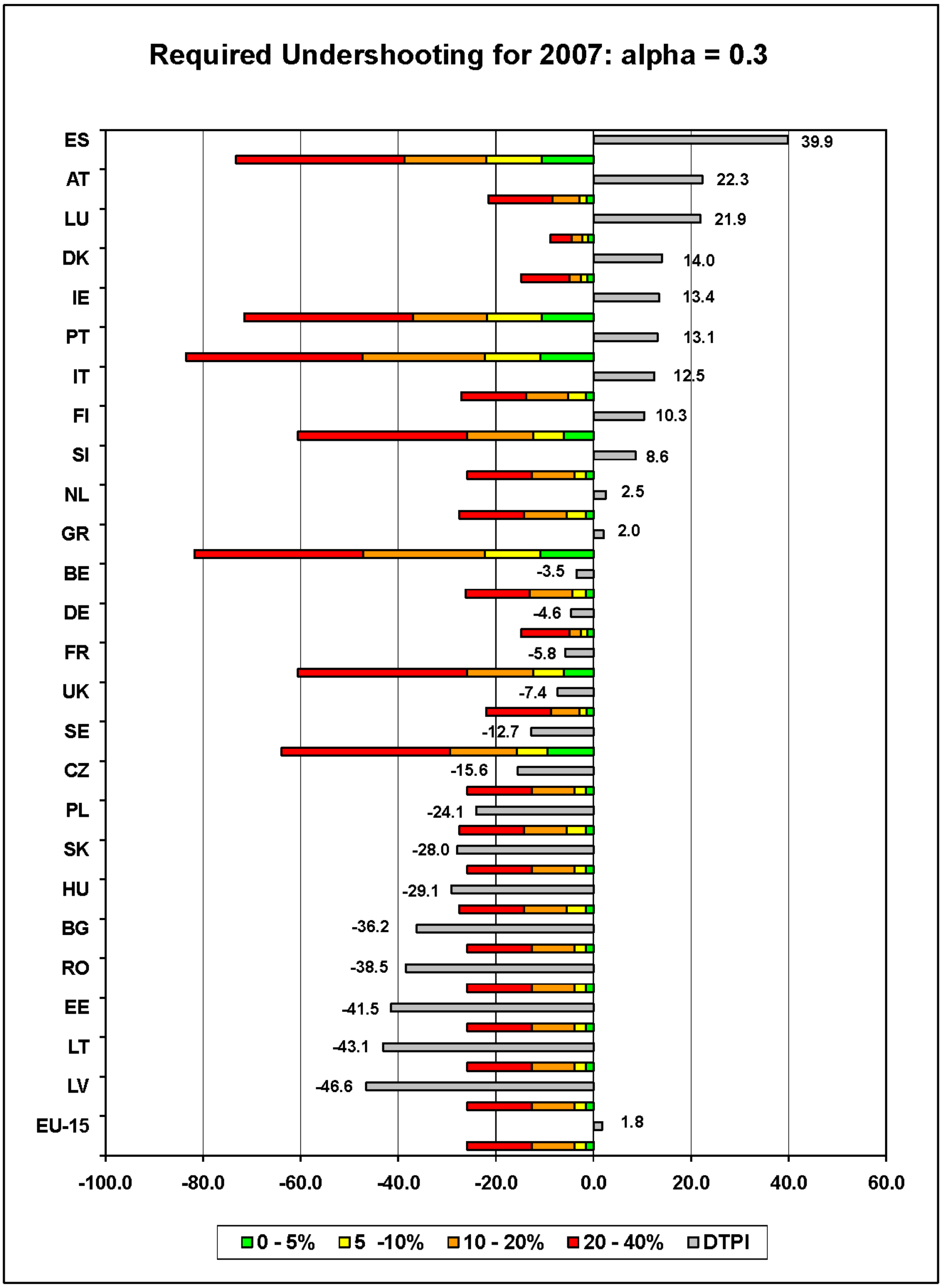

Figure 7: U by ρ (see intervals) for $\alpha = 0.3$ in addition to the DTPI.

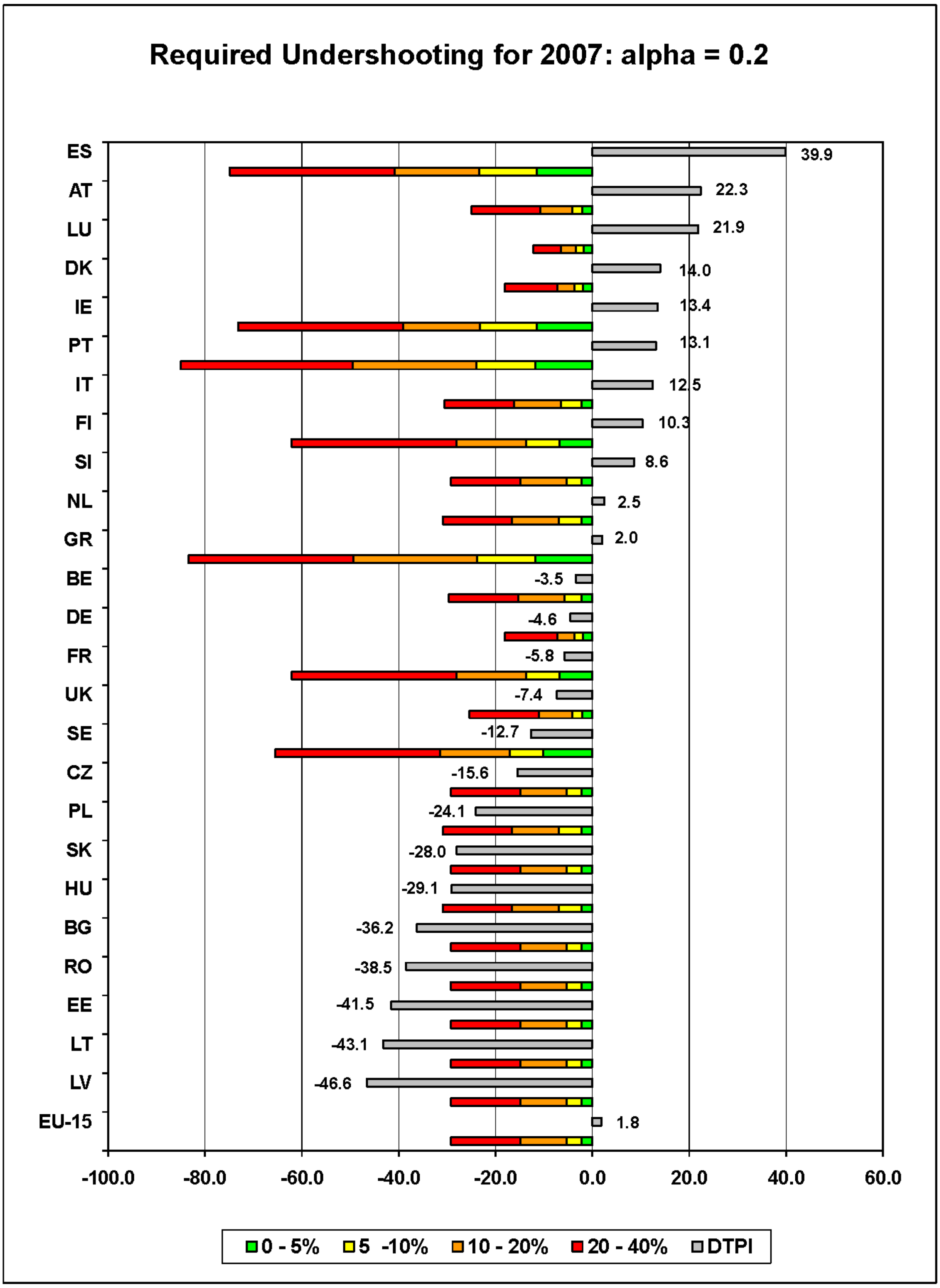

Figure 8: U by ρ (see intervals) for $\alpha = 0.2$ in addition to the DTPI.

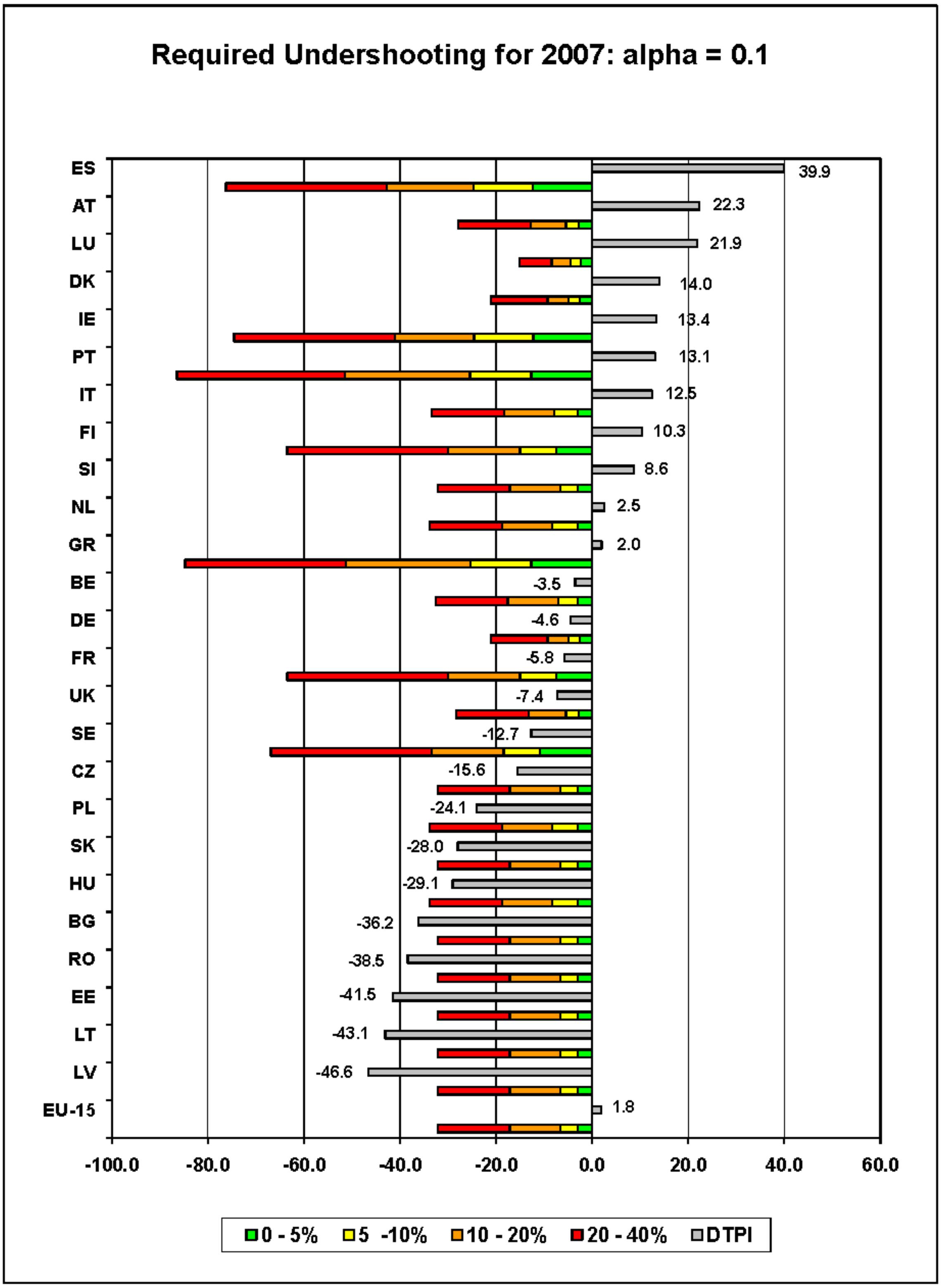

Figure 9: U by ρ (see intervals) for $\alpha = 0.1$ in addition to the DTPI.

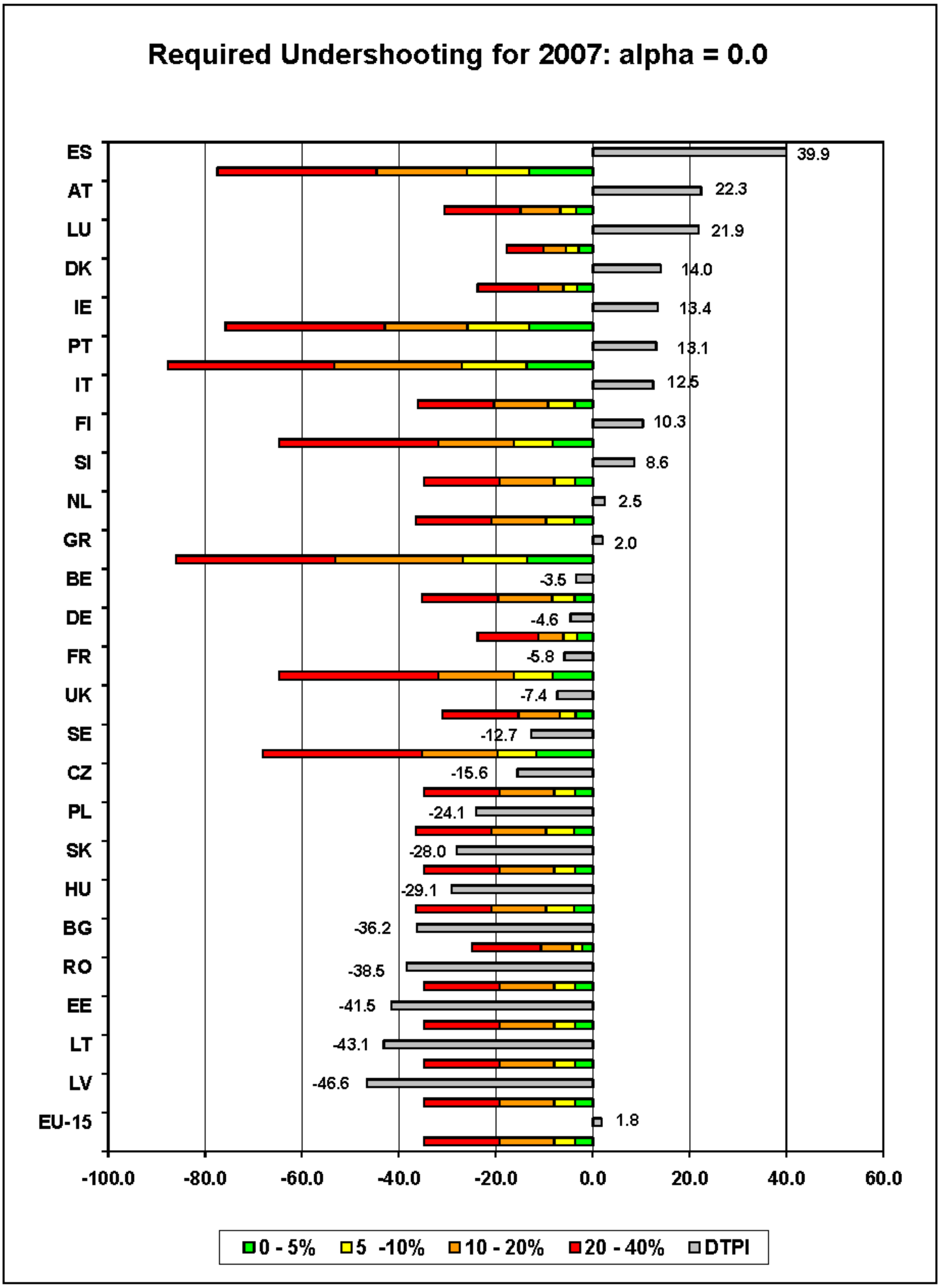

Figure 10: U by ρ (see intervals) for $\alpha = 0.0$ in addition to the DTPI.

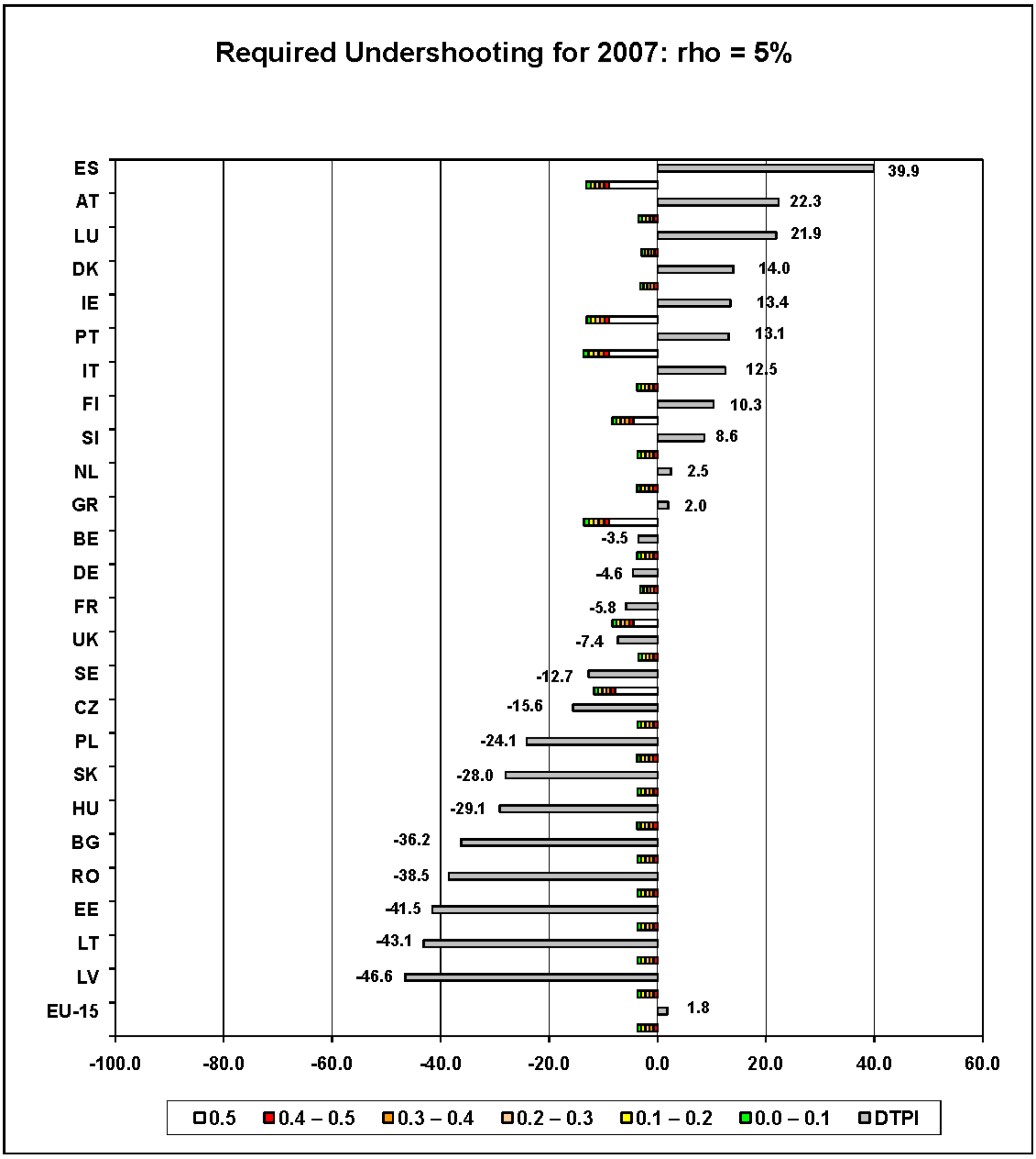

Figure 11: U by α (see value and intervals) for $\rho = 5\%$ in addition to the DTPI.

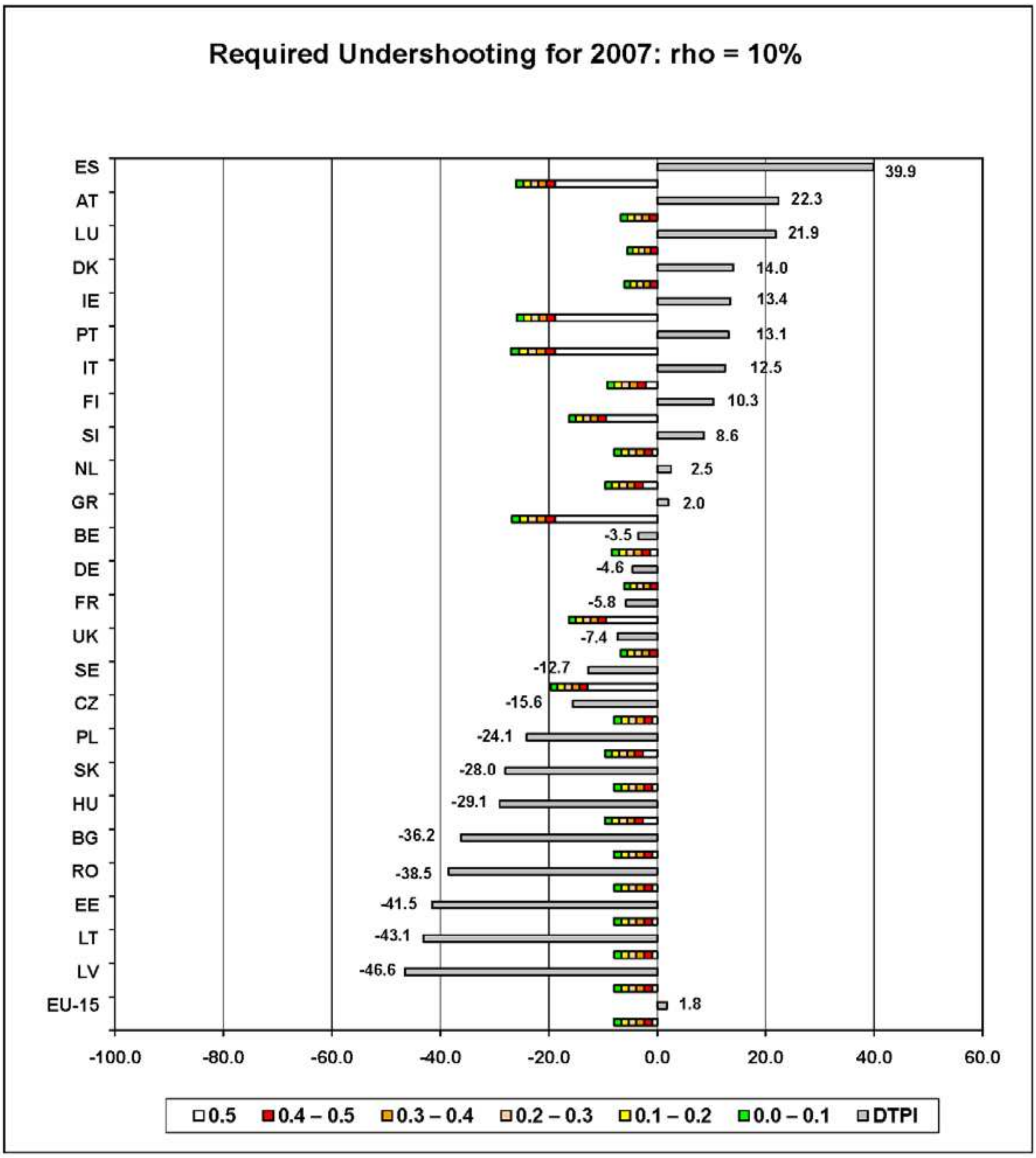

Figure 12: U by α (see value and intervals) for $\rho = 10\%$ in addition to the DTPI.

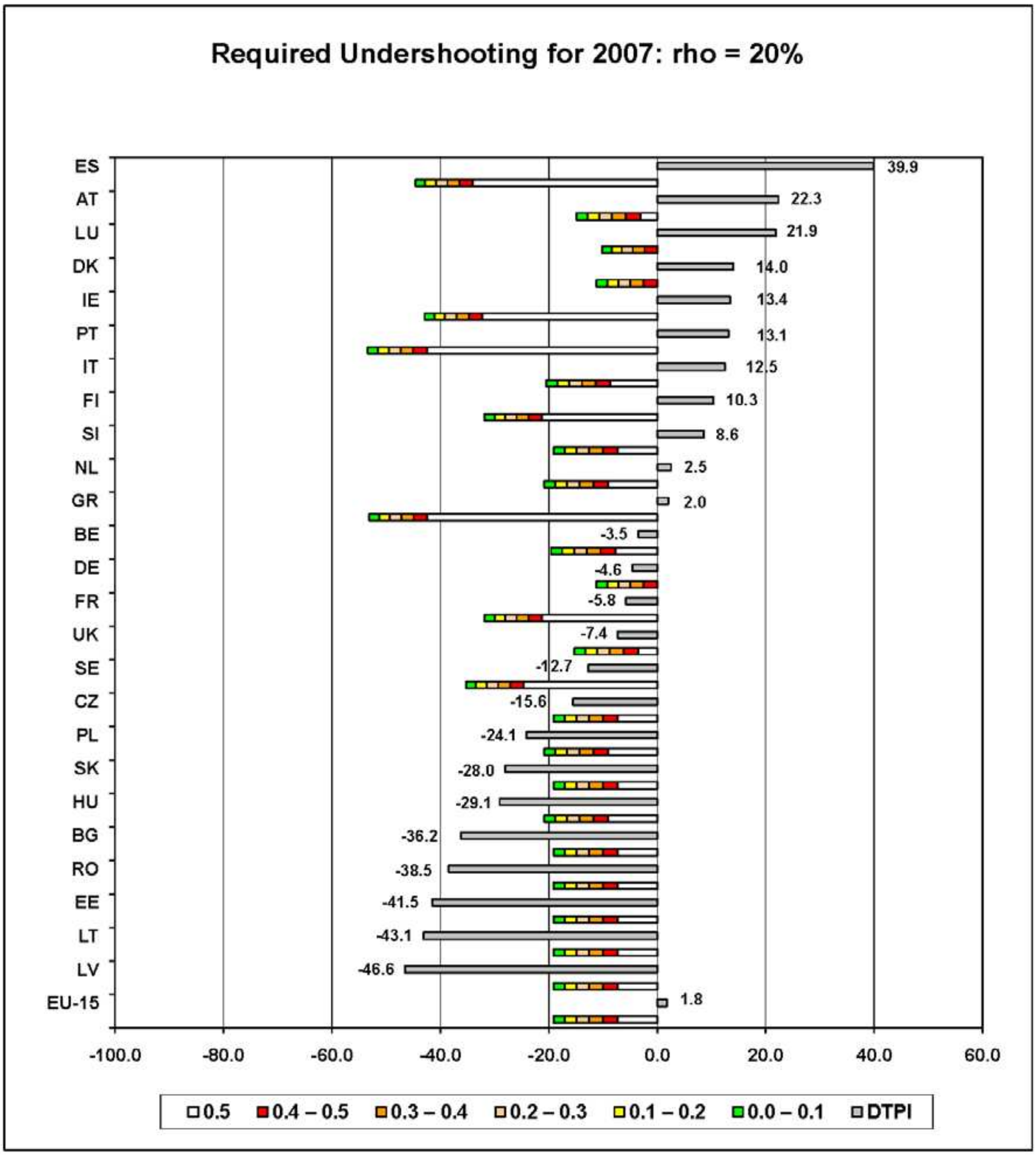

Figure 13: U by α (see value and intervals) for $\rho = 20\%$ in addition to the DTPI.

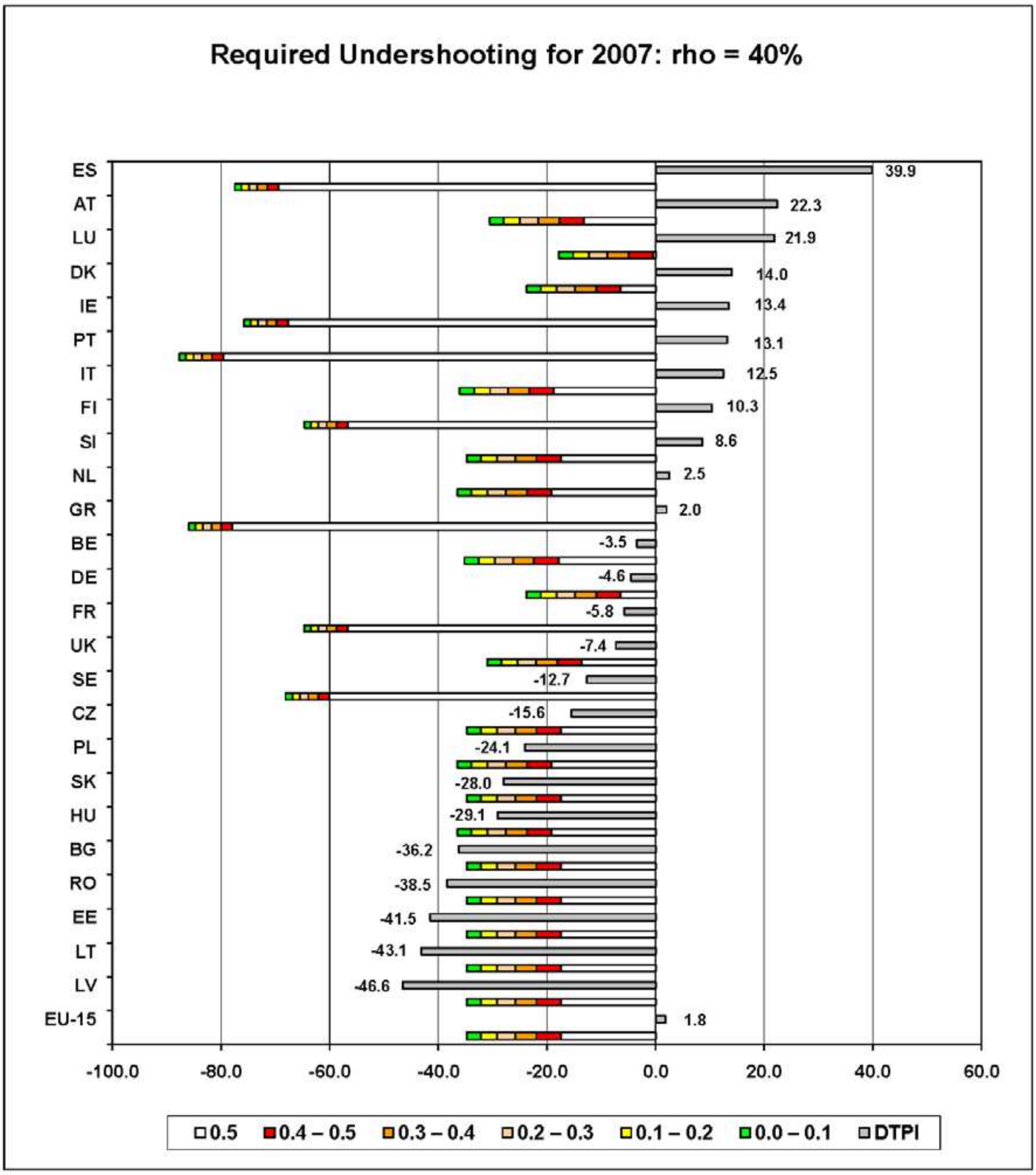

Figure 14: U by α (see value and intervals) for $\rho = 40\%$ in addition to the DTPI.

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Supporting online material (SOM):

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Acronyms and Nomenclature

CH_4	methane
CO_2	carbon dioxide
EU	European Union
DTPI	distance-to-target-path indicator
GHG	greenhouse gas
HFC	hydrofluorocarbon
IPCC	Intergovernmental Panel on Climate Change
KP	Kyoto Protocol
KT	Kyoto (emissions) target
LUCF	land-use change and forestry
MS	Member State
N_2O	nitrous oxide
PFC	perfluorocarbon
SF_6	sulfur hexafluoride
SOM	supporting online material
Und	undershooting
Und&VT	undershooting and verification time
VT	verification time
crit	critical
mod	modified
t	true

ISO Country Code

AT	Austria
BE	Belgium
BG	Bulgarian
CY	Cyprus
CZ	Czech Republic
DE	Germany
DK	Denmark
EE	Estonia
ES	Spain
FI	Finland
FR	France
GR	Greece
HU	Hungary
IE	Ireland
IT	Italy
LT	Lithuania
LU	Luxembourg
LV	Latvia
MT	Malta
NL	Netherlands
PL	Poland
PT	Portugal
RO	Romania
SE	Sweden
SI	Slovenia
SK	Slovakia
UK	United Kingdom

Appendix

Below the inversions $\rho = \rho(\delta_{KP}, U, \alpha)$ of Eq. (6), (9), (13) and (17) are derived. They are used to determine the maximal uncertainties with which Member States with DTPI < 0 can report to meet a given risk α that their true emissions in the commitment year/period fall above their true emission targets.

Case 1: $\delta_{KP} > 0 : \delta_{crit} \leq \delta_{KP}$. Eq. (6) for $\alpha = 0.5$ and $0 \leq \alpha < 0.5$:

α = 0.5:

$$U = 0 \text{ for all } \rho. \tag{A1}$$

0 ≤ α < 0.5:

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

$$(1-\delta_{KP})\left(1 - \frac{(1-2\alpha)\rho}{1+(1-2\alpha)\rho}\right) = 1 - (\delta_{KP} + U) \tag{A2a}$$

$$(1-\delta_{KP})\frac{1}{1+(1-2\alpha)\rho} = 1 - \delta_{mod}. \tag{A2b}$$

With $KT := 1-\delta_{KP}$ as the agreed Kyoto (emissions) target and $KT_{mod} := 1-\delta_{mod} = 1-(\delta_{KP}+U)$ the corresponding, or modified, Kyoto (emissions) target which encompasses undershooting:

$$(1-2\alpha)\rho = \frac{KT}{KT_{mod}} - 1 \tag{A3}$$

$$\rho = \frac{U}{(1-2\alpha)KT_{mod}}. \tag{A4}$$

Case 2: $\delta_{KP} > 0 : \delta_{crit} > \delta_{KP}$. Eq. (9) in combination with Eq. (10) for $\alpha = 0.5$ and $0 \leq \alpha < 0.5$:

α = 0.5:

$$U = U_{Gap} = \frac{\rho}{1+\rho} - \delta_{KP} \tag{A5), (A6}$$

in combination with Eq. (1a). Thus:

$$\frac{\rho}{1+\rho} = \delta_{mod} \tag{A7}$$

$$\rho = \frac{\delta_{mod}}{1-\delta_{mod}}. \tag{A8}$$

$\underline{0 \leq \alpha < 0.5:}$

$$U = 1 - (1 - \delta_{crit}) - \delta_{KP} + (1 - \delta_{crit}) \frac{(1 - 2\alpha)\rho}{1 + (1 - 2\alpha)\rho} \tag{A9}$$

$$(1 - \delta_{crit}) \left(1 - \frac{(1 - 2\alpha)\rho}{1 + (1 - 2\alpha)\rho} \right) = 1 - (\delta_{KP} + U). \tag{A10}$$

In combination with Eq. (1a):

$$\left(1 - \frac{\rho}{1 + \rho} \right) \left(1 - \frac{(1 - 2\alpha)\rho}{1 + (1 - 2\alpha)\rho} \right) = KT_{mod} \tag{A11a}$$

$$\left(\frac{1}{1 + \rho} \right) \left(\frac{1}{1 + (1 - 2\alpha)\rho} \right) = KT_{mod} \tag{A11b}$$

$$(1 + \rho)(1 + (1 - 2\alpha)\rho) = \frac{1}{KT_{mod}} \tag{A11c}$$

$$1 + (1 - 2\alpha)\rho + \rho + (1 - 2\alpha)\rho^2 = \frac{1}{KT_{mod}} \tag{A11d}$$

$$\rho^2 + 2\frac{1 - \alpha}{1 - 2\alpha}\rho - \frac{1 - KT_{mod}}{(1 - 2\alpha)KT_{mod}} = 0 \tag{A11e}$$

$$\rho_{1,2} = -\frac{1 - \alpha}{1 - 2\alpha} \pm \sqrt{\left(\frac{1 - \alpha}{1 - 2\alpha} \right)^2 + \frac{1 - KT_{mod}}{(1 - 2\alpha)KT_{mod}}}. \tag{A12a,b}$$

Eq. (A12a) provides the correct solution.

Case 3: $\delta_{KP} \leq 0 : \delta_{crit} < \delta_{KP}$. Eq. (13) in combination with Eq. (14) for $\alpha = 0.5$ and $0 \leq \alpha < 0.5$:

α = 0.5:

$$U = U_{Gap} = \frac{\rho}{1-\rho} - \delta_{KP} \qquad \text{(A5), (A13)}$$

in combination with Eq. (1b). Thus:

$$\frac{\rho}{1-\rho} = \delta_{mod} \qquad \text{(A14)}$$

$$\rho = \frac{\delta_{mod}}{1+\delta_{mod}}. \qquad \text{(A15)}$$

0 ≤ α < 0.5:

$$U = 1-(1+\delta_{crit}) - \delta_{KP} + (1+\delta_{crit})\frac{(1-2\alpha)\rho}{1+(1-2\alpha)\rho} \qquad \text{(A16)}$$

$$(1+\delta_{crit})\left(1-\frac{(1-2\alpha)\rho}{1+(1-2\alpha)\rho}\right) = 1-[\delta_{KP}+U]. \qquad \text{(A17)}$$

In combination with Eq. (1b):

$$\left(1-\frac{\rho}{1-\rho}\right)\left(1-\frac{(1-2\alpha)\rho}{1+(1-2\alpha)\rho}\right) = KT_{mod} \qquad \text{(A18a)}$$

$$\left(\frac{1-2\rho}{1-\rho}\right)\left(\frac{1}{1+(1-2\alpha)\rho}\right) = KT_{mod} \qquad \text{(A18b)}$$

$$1-2\rho = KT_{mod} + (1-2\alpha)KT_{mod}\rho - KT_{mod}\rho - (1-2\alpha)KT_{mod}\rho^2 \qquad \text{(A19)}$$

$$\rho^2 - 2\frac{1-\alpha KT_{mod}}{(1-2\alpha)KT_{mod}}\rho + \frac{1-KT_{mod}}{(1-2\alpha)KT_{mod}} = 0 \qquad \text{(A20)}$$

$$\rho_{1,2} = \frac{1-\alpha KT_{mod}}{(1-2\alpha)KT_{mod}} \pm \sqrt{\left(\frac{1-\alpha KT_{mod}}{(1-2\alpha)KT_{mod}}\right)^2 - \frac{1-KT_{mod}}{(1-2\alpha)KT_{mod}}}. \qquad \text{(A21a,b)}$$

Eq. (A21b) provides the correct solution.

Case 4: $\delta_{KP} \leq 0 : \delta_{crit} \geq \delta_{KP}$. Eq. (17) in combination with Eq. (18) and (19) for $\alpha = 0.5$ and $0 \leq \alpha < 0.5$:

α = 0.5:

$$U = U_{Gap} = \frac{2\rho}{1-\rho} \qquad \text{(A5), (A22)}$$

in combination with Eq. (1b). Thus:

$$\rho = \frac{U}{2+U}. \tag{A23}$$

$\underline{0 \leq \alpha < 0.5:}$

$$U = 1-\delta_{KP} - \left(1-\delta_{KP}+2\delta_{crit}\right) + \left(1-\delta_{KP}+2\delta_{crit}\right)\frac{\left(1-2\alpha\right)\rho}{1+\left(1-2\alpha\right)\rho} \tag{A24}$$

$$\left(1-\delta_{KP}+2\delta_{crit}\right)\left(1-\frac{\left(1-2\alpha\right)\rho}{1+\left(1-2\alpha\right)\rho}\right) = 1-\left(\delta_{KP}+U\right). \tag{A25}$$

In combination with Eq. (1b):

$$\left(KT-2\frac{\rho}{1-\rho}\right)\left(1-\frac{\left(1-2\alpha\right)\rho}{1+\left(1-2\alpha\right)\rho}\right) = KT_{mod}. \tag{A26a}$$

$$\left(\frac{KT-\left(2+KT\right)\rho}{1-\rho}\right)\left(\frac{1}{1+\left(1-2\alpha\right)\rho}\right) = KT_{mod} \tag{A26b}$$

$$KT-\left(2+KT\right)\rho = KT_{mod}+\left(1-2\alpha\right)KT_{mod}\rho - KT_{mod}\rho - \left(1-2\alpha\right)KT_{mod}\rho^2 \tag{A27}$$

$$\rho^2 - 2\frac{1+\frac{KT}{2}-\alpha KT_{mod}}{\left(1-2\alpha\right)KT_{mod}}\rho + \frac{U}{\left(1-2\alpha\right)KT_{mod}} = 0 \tag{A28}$$

$$\rho_{1,2} = \frac{1+\frac{KT}{2}-\alpha KT_{mod}}{\left(1-2\alpha\right)KT_{mod}} \pm \sqrt{\left(\frac{1+\frac{KT}{2}-\alpha KT_{mod}}{\left(1-2\alpha\right)KT_{mod}}\right)^2 - \frac{U}{\left(1-2\alpha\right)KT_{mod}}}. \tag{A29a,b}$$

Eq. (A29b) provides the correct solution.

Table A1 provides the maximal uncertainties with which individual Member States with DTPI < 0 can report to meet a given risk $0 \leq \alpha \leq 0.5$ that their true emissions in the commitment year/period fall above their true emission targets.

Table A1: Maximal uncertainties with which Member States (MS) with DTPI < 0 can report to meet a given risk α that their true emissions in the commitment year/period fall above their true emission targets (see Fig. 5–10). Note that the inverse equations $\rho = \rho(\delta_{KP}, U, \alpha)$ in the Appendix refer to 2008/12; i.e., the Member States' DTPIs for 2007 must be multiplied with (-20/17). Example: To meet $\alpha = 0.2$, the CZ can report with an uncertainty ρ of 20.7% owing to its DTPI of -15.6% (or 18.3% if multiplied with (-20/17); see Fig. 9).

MS	δ_{KP} %	α 1	DTPI 1	ρ 1	Case	Eq.
BE	7.5	0.0	0.041	0.047	Case 1	(A4)
		0.1	0.041	0.059	Case 1	(A4)
		0.2	0.041	0.078	Case 1	(A4)
		0.3	0.041	0.092	Case2	(A12a)
		0.4	0.041	0.108	Case2	(A12a)
		0.5	0.041	0.132	Case2	(A8)
BG	8.0	0.0	0.426	0.423	Case 2	(A12a)
		0.1	0.426	0.471	Case 2	(A12a)
		0.2	0.426	0.534	Case 2	(A12a)
		0.3	0.426	0.622	Case 2	(A12a)
		0.4	0.426	0.759	Case 2	(A12a)
		0.5	0.426	> 1.0	Case 2	(A8)
CZ	8.0	0.0	0.183	0.165	Case 2	(A12a)
		0.1	0.183	0.183	Case 2	(A12a)
		0.2	0.183	0.207	Case 2	(A12a)
		0.3	0.183	0.239	Case 2	(A12a)
		0.4	0.183	0.284	Case 2	(A12a)
		0.5	0.183	0.357	Case 2	(A8)
EE	8.0	0.0	0.489	0.523	Case 2	(A12a)
		0.1	0.489	0.582	Case 2	(A12a)
		0.2	0.489	0.661	Case 2	(A12a)
		0.3	0.489	0.772	Case 2	(A12a)
		0.4	0.489	0.949	Case 2	(A12a)
		0.5	0.489	> 1.0	Case 2	(A8)
FR	0.0	0.0	0.068	0.035	Case 3	(A21b)
		0.1	0.068	0.038	Case 3	(A21b)
		0.2	0.068	0.043	Case 3	(A21b)
		0.3	0.068	0.048	Case 3	(A21b)
		0.4	0.068	0.055	Case 3	(A21b)
		0.5	0.068	0.064	Case 3	(A15)
DE	21.0	0.0	0.054	0.073	Case 1	(A4)
		0.1	0.054	0.091	Case 1	(A4)
		0.2	0.054	0.122	Case 1	(A4)
		0.3	0.054	0.183	Case 1	(A4)
		0.4	0.054	0.285	Case 2	(A12a)
		0.5	0.054	0.358	Case 2	(A8)
HU	6.0	0.0	0.342	0.293	Case 2	(A12a)
		0.1	0.342	0.326	Case 2	(A12a)
		0.2	0.342	0.369	Case 2	(A12a)
		0.3	0.342	0.428	Case 2	(A12a)
		0.4	0.342	0.516	Case 2	(A12a)
		0.5	0.342	0.673	Case 2	(A8)
LV	8.0	0.0	0.548	0.639	Case 2	(A12a)
		0.1	0.548	0.712	Case 2	(A12a)
		0.2	0.548	0.809	Case 2	(A12a)
		0.3	0.548	0.948	Case 2	(A12a)
		0.4	0.548	>1.0	Case 2	(A12a)
		0.5	0.548	>1.0	Case 2	(A8)

Table A1: continued.

LT	**8.0**	0.0	0.507	0.557	Case 2	(A12a)
		0.1	0.507	0.620	Case 2	(A12a)
		0.2	0.507	0.704	Case 2	(A12a)
		0.3	0.507	0.824	Case 2	(A12a)
		0.4	0.507	>1.0	Case 2	(A12a)
		0.5	0.507	> 1.0	Case 2	(A8)
PL	**6.0**	0.0	0.284	0.234	Case 2	(A12a)
		0.1	0.284	0.261	Case 2	(A12a)
		0.2	0.284	0.295	Case 2	(A12a)
		0.3	0.284	0.341	Case 2	(A12a)
		0.4	0.284	0.408	Case 2	(A12a)
		0.5	0.284	0.523	Case 2	(A8)
RO	**8.0**	0.0	0.453	0.463	Case 2	(A12a)
		0.1	0.453	0.515	Case 2	(A12a)
		0.2	0.453	0.584	Case 2	(A12a)
		0.3	0.453	0.681	Case 2	(A12a)
		0.4	0.453	0.833	Case 2	(A12a)
		0.5	0.453	> 1.0	Case 2	(A8)
SK	**8.0**	0.0	0.330	0.302	Case 2	(A12a)
		0.1	0.330	0.336	Case 2	(A12a)
		0.2	0.330	0.380	Case 2	(A12a)
		0.3	0.330	0.441	Case 2	(A12a)
		0.4	0.330	0.532	Case 2	(A12a)
		0.5	0.330	0.694	Case 2	(A8)
SE	**-4.0**	0.0	0.150	0.056	Case 3	(A21b)
		0.1	0.150	0.062	Case 3	(A21b)
		0.2	0.150	0.068	Case 3	(A21b)
		0.3	0.150	0.076	Case 3	(A21b)
		0.4	0.150	0.086	Case 3	(A21b)
		0.5	0.150	0.099	Case 3	(A15)
UK	**12.5**	0.0	0.087	0.110	Case 1	(A4)
		0.1	0.087	0.137	Case 1	(A4)
		0.2	0.087	0.158	Case 2	(A12a)
		0.3	0.087	0.182	Case 2	(A12a)
		0.4	0.087	0.216	Case 2	(A12a)
		0.5	0.087	0.268	Case 2	(A8)

Endnotes

[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 on 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 base year and commitment year/period is a straight line, and emissions prior to the base year are 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 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.*, 2004: Section 2.3).

[3] For earlier evaluations see Overview of Background and Monitoring Reports.

[4] For example, Ireland is allowed a 13% increase from 1990 levels by 2008–2012, so its theoretical linear target for 2007 is a rise of no more than 11.1%. Its actual emissions in 2007 show an increase of 24.5% since 1990; hence, its DTPI is 24.5 – 11.1, or 13.4 percentage points. Germany's Kyoto target is a 21% reduction, while its theoretical linear target for 2007 is a decrease of 17.9%. Its actual emissions in 2007 were 22.4% lower than in 1990; hence, Germany's DTPI is (-22.4) - (-17.9), or -4.6 percentage points.

[5] 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 which is equal to approximately two standard deviations if the emission values are normally distributed) (Penman *et al.*, 2000: p. 6.6).

[6] Austria has, with reference to 1990, as the only EU-27 Member State carried out full carbon accounting (Jonas and Nilsson, 2001: Tab. 14). It served as a basis for extracting a partial carbon account which additionally encompasses CH_4 and N_2O and which is in line with the IPCC Guidelines relevant at the time (IPCC, 1997a,b,c). The 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 $CO_2 + CH_4 + N_2O$.

[7] Here, δ_{KP} specifies the normalized emission change, to which the Member States agreed under the EU burden sharing (δ_{EU_MS}). This change can be different from that agreed under the Kyoto Protocol. However, δ_{KP} is continued to be used to simplify indexing.

[8] The linear target path is established for all countries between 1990 and 2010, irrespective of whether or not 1990 is the base year for their CO_2-CH_4-N_2O emissions, the determining system gases (see Jonas *et al.*, 2004: Section 3). We follow this common practice to be in agreement with the DTPI reporting of the EU.

9 Note that in Cases 3 and 4, unlike in Jonas *et al.* (2008: SOM: Appendix D), the critical emission limitation or reduction δ_{crit} is not adjusted.