International Institute for
Applied Systems Analysis
Schlossplatz 1
A-2361 Laxenburg, Austria

Tel: +43 2236 807 342
Fax: +43 2236 71313
E-mail: publications@iiasa.ac.at
Web: www.iiasa.ac.at

Interim Report IR-11-004

Preparatory Signal Detection for the EU-27 Member States Under EU Burden Sharing—Advanced Monitoring Including Uncertainty (1990–2006)

Andriy Bun (andr.bun@gmail.com)
Khrystyna Hamal (kh.hamal@gmail.com)
Matthias Jonas (jonas@iiasa.ac.at)

Approved by

Anatoly Shvidenko
Acting Program Leader, Ecosystems Management & Services Program

28 April 2011

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 2006.

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 2006

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 2006 thirteen EU-27 Member States exhibit a negative DTPI (not counting Belgium with a $\mathrm{DTPI} \approx 0$) and thus appear as potential sellers: Bulgaria, the 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 ($a \approx 0.1$) that the Member States' true emissions in the commitment year/period fall above their true emission targets. As of 2006, these conditions can only be met by ten (nine new and one old) Member States (ranked in terms of credibility): Estonia, Latvia, Lithuania, Bulgaria, Romania, Slovakia, Hungary, Poland, the Czech Republic and the United Kingdom; while three old Member States, Germany, Sweden and France, can only act as potential sellers with a higher risk (Germany and Sweden: $\alpha \approx 0.35$; France: $\alpha = 0.5$). The other EU-27 Member States do not meet their linear path (base year–commitment year) undershooting targets as of 2005 (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

Andriy Bun and Khrystyna Hamal are postdoc researchers and serve as Research Assistants at Lviv National Polytechnic University. Andriy Bun also serves as a Research Assistant in IIASA's Ecosystems Management & Services Program.

Matthias Jonas is a Senior Research Scholar in IIASA's Ecosystems Management & Services Program.

Preparatory Signal Detection for the EU-27 Member States Under EU Burden Sharing—Advanced Monitoring Including Uncertainty (1990–2006)

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 2006 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 2006. 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 (2006) 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, 2008a: Tab. ES.1 and 2.1; EEA, 2008b: Fig. 3.2 and Tab. 11.1).[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 2006 and their linear path targets for that year. Figure 3 facilitates understanding the 2006 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 2006, i.e., the linear target path 1990–2008/12 is evaluated with respect to this year.

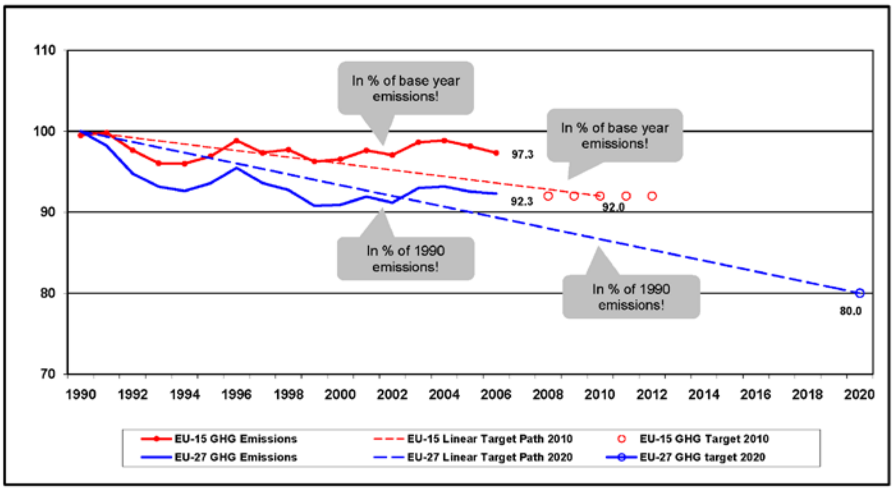

Figure 1: EU-27 GHG emissions for 1990–2006 (excluding LUCF and Kyoto mechanisms) with 1990 emissions as reference. The corresponding EU-15 GHG emissions and linear target path 1990–2008/12, with base-year emissions as reference, are shown for comparison. Source: EEA (2008a: Fig. ES.1 and ES.2; reproduced).

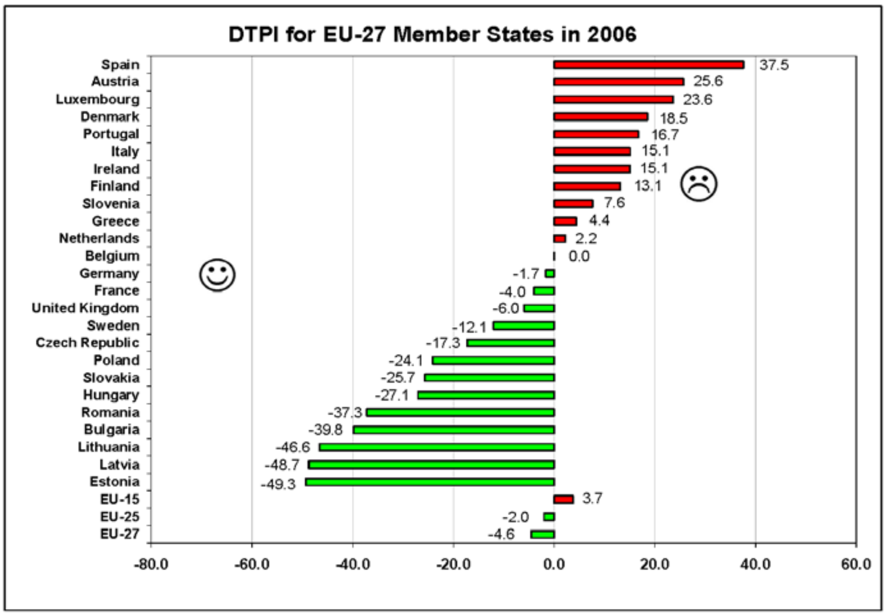

Figure 2: Distance-to-target-path indicator (DTPI) for the EU-27 as a whole and its Member States in 2006 under the Kyoto Protocol and EU burden sharing (excluding LUCF and Kyoto mechanisms). The DTPIs for the EU-15 and EU-25 as a whole are shown for comparison.

Table 1: Gap (2006–Kyoto target) for the EU-27 as a whole and its Member States in 2008/12 under the Kyoto Protocol and EU burden sharing (excluding and including LUCF and Kyoto mechanisms; see last column). This gap indicator is identical to the distance-to-target-path indicator (DTPI) with reference to 2008/12, not 2006 which is not reported by the EEA. 2nd and 3rd column: base year and 2006 GHG emissions (in CO_2-equivalent); 4th and 5th column: 2005–2006 and base year–2006 emission changes (in %); 6th and 7th column: 2008–2012 emission targets under the Kyoto Protocol and EU burden sharing (in % and CO_2-equivalent). Values for the EU-15 as a whole are shown for comparison. Sources: EEA (2008b: Fig. 3.2 and Tab. 11.1).

Country	**Base-year emissions (1)**	**2006 emissions**	**Change 2005–2006**	**Change 2006/ base-year emissions**	**EU burden-sharing or Kyoto target**		**Gap (2006 — Kyoto target) without/with Kyoto mechanisms and carbon sinks (2)**
	Mt CO_2-eq .	Mt CO_2-eq.	%	%	%	Mt CO_2-eq.	% relative to base-year emissions
Austria	79.05	91.1	− 2.3	+15.2	− 13.0	68.8	+ 28.2/+ 16.0
Belgium	145.7	137.0	− 3.8	− 6.0	− 7.5	134.8	+ 1.5/− 3.3
Bulgaria	132.6	71.3	1.2	− 46.2	− 8.0	122.0	− 38.2/n.a.
Cyprus (1)	6.0 (1)	10.0	1.6	+66.0 (1)	No target	No target	No target
Czech Republic	194.2	148.2	1.7	− 23.7	− 8.0	178.7	− 15.7/− 16.3
Denmark	69.3	70.5	10.9	+1.7	− 21.0	54.8	+ 22.7/+ 13.3
Estonia	42.6	18.9	− 2.3	− 55.7	− 8.0	39.2	− 47.7/− 47.7
Finland	71.0	80.3	16.3	+13.1	0.0	71.0	+13.1/+10.3
France	563.9	541.3	− 2.5	− 4.0	0.0	563.9	− 4.0/− 4.7
Germany	1 232.4	1 004.8	0.0	− 18.5	− 21.0	973.6	+ 2.5/+ 2.2
Greece	107.0	133.1	− 0.5	+24.4	25.0	133.7	− 0.6/− 1.7
Hungary	115.4	78.6	− 2.0	− 31.9	− 6.0	108.5	− 25.9/n.a.
Ireland	55.6	69.8	− 0.8	+25.5	13.0	62.8	+ 12.5/+ 2.3
Italy	516.9	567.9	− 1.7	+9.9	− 6.5	483.3	+ 16.4/+ 7.5
Latvia	25.9	11.6	4.4	− 55.1	− 8.0	23.8	− 47.1/n.a.
Lithuania	49.4	23.2	2.4	− 53.0	− 8.0	45.5	− 45.0/n.a.
Luxembourg	13.2	13.3	0.2	+1.2	-28.0	9.5	+ 29.2/− 0.8
Malta (1)	2.2 (1)	3.2	− 0.3	+45.2 (1)	No target	No target	No target
Netherlands	213.0	207.5	− 2.0	− 2.6	− 6.0	200.3	+ 3.4/− 2.8
Poland	563.4	400.5	3.7	-28.9	− 6.0	529.6	− 22.9/− 23.5
Portugal	60.1	83.2	− 4.8	+38.3	27.0	76.4	+ 11.3/− 6.1
Romania	278.2	156.7	3.1	− 43.7	− 8.0	256.0	− 35.7/n.a.
Slovakia	72.1	48.9	− 0.9	− 32.1	− 8.0	66.3	− 24.1/n.a.
Slovenia	20.4	20.6	0.6	+1.2	− 8.0	18.7	+ 9.2/− 2.0
Spain	289.8	433.3	− 1.7	+49.5	15.0	333.2	+ 34.5/+ 12.6
Sweden	72.2	65.7	− 1.7	− 8.9	4.0	75.0	− 12.9/− 15.8
United Kingdom	776.3	652.3	− 0.5	− 16.0	− 12.5	679.3	− 3.5/− 4.0
EU-15	**4 265.5**	**4 151.1**	**− 0.8**	**− 2.7**	**− 8.0**	**3.924.3**	**+ 5.3/+ 1.0**
EU-27 (1)	**5 572.2 (1)**	**5 142.8**	**− 0.3**	**− 7.7 (1)**	**No target**	**No target**	**No target**
Croatia	36.0	30.8	0.9	− 14.4	− 5.0	34.2	− 9.4/− 12.1
Iceland	3.4	4.2	14.2	+25.7	10.0	3.7	+ 15.7/n.a.
Liechtenstein	0.2	0.3	0.9	+19.0	− 8.0	0.2	+ 27.0/+ 9.6
Norway	49.6	53.5	− 0.5	+7.8	1.0	50.1	+ 6.8/− 10.1
Switzerland	52.8	53.2	− 1.1	+0.8	− 8.0	48.6	+ 8.8/+ 5.8
Turkey (1)	170.1 (1)	331.8	6.2	+95.1 (1)	No target	No target	No target

Note: (1) 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.
(2) The gap (2006-Kyoto target) measures the deviation in percentage points of actual emissions in 2006 from the burden-sharing target for 2010, relative to the base-year. A positive value indicates an underachievement and a negative value an overachievement by 2006.
n.a.: the country does not intend to use carbon sinks or Kyoto mechanisms to meet its target.

Source: EEA, based on EU Member States greenhouse gas inventories.

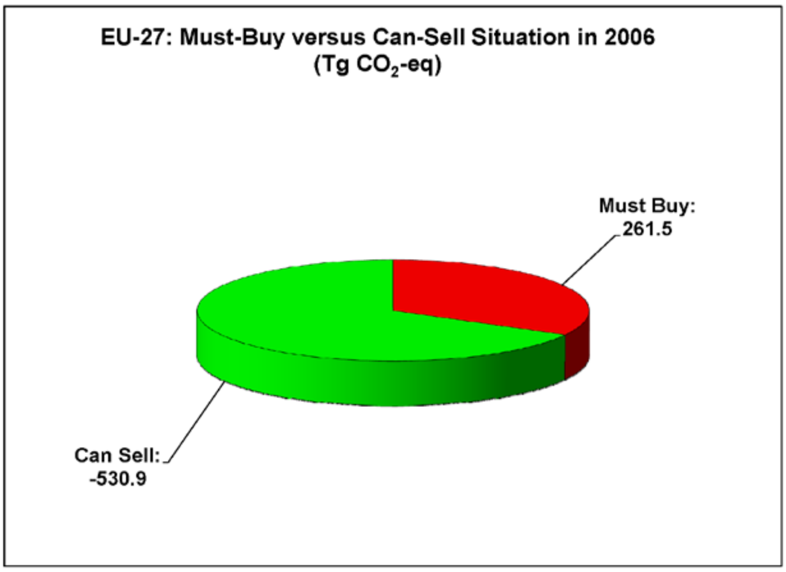

Figure 3: Figure 2 presented in absolute terms. Member States appearing as potential buyers in 2006: AT, DK, ES, FI, GR, IE, IT, LU, NL, PT, SI; Member States appearing as potential sellers in 2006: BG, CZ, DE, EE, FR, HU, LT, LV, PL, RO SE, SK, UK. BE's DTPI is zero. Member States not considered: CY, 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 (2008a: Tab. 1.15 and 1.16) and is reproduced as Table 2 below. This compilation makes available quantified uncertainty estimates from twenty-six of the EU-27 Member States (extracted from their 2008 or earlier National Inventory Reports; cf. second row in Tab. 2). Malta provided its national inventory report but without uncertainty estimates. 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). Six Member States – Cyprus, Denmark, Germany, Poland, Portugal and Slovakia – 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 Cyprus, Denmark, Germany, Poland, Portugal and Slovakia) and Kyoto mechanisms.[6] Source: EEA (2008a: Tab. 1.15 and 1.16).

Member State	**Austria**		**Belgium**	**Denmark**	**Finland**		**France**	**Germany**	**Greece**
Citation	NIR Apr 2008, pp.46-54		NIR Apr 2008, pp. 17-23+ Uncertainty Table	Uncerainty table + NIR Apr 2008 pp.51-54	NIR Apr 2008, pp. 30-32		NIR, March 2007, pp. 53-56 + uncertainty table	NIR Apr 2008 , pp. 88-91	Uncertainty Table
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	Yes	Yes (Annex 1)		Yes	Yes (almost): Annex 7	Yes
Years and sectors included	emissions: 2006; trends: 1990-2006; almost all categories (e. L.)		emissions: 2005 and 2006; trends: BY-2005 and BY-2006; all categories, (e. L.)	emissions: 2006; trend BY-2006; all categories	emissions: 1990, 2006; trends: BY-2006; almost all categories		emissions: 2006; trends: 1990-2006; all categories	emissions: 2006; all categories (i.L.)	emissions: 2006; trend: BY-2006; almost all categories (>99%)
Uncertainty (%)	Tier 1	Tier 2	Tier 1	Tier 1 (i. L.)	Tier 1 (i. L.)	Tier 2 (e. L.)	Tier 1	Tier 1	Tier 1
CO_2				2.9%					i. L.: 4.8% e. L.: 3.5%
CH_4				24%					i. L.: 31.9% e. L.: 37.9%
N_2O				50%					i. L.: 81.8 e. L.: 81.8%
F-gases				48%					i. L.: 127.2% e. L.: 127.2%
Total	3.8%	5.3%	2005: 7.7% 2006 7.6%	5.7%	2006: 50.1%	1990: -10%/+10% 2006: 0%/+0%	i. L.: 22% e. L.: 17.6%	12.5%	i. L.: 10% e. L.: 9.3%
Uncertainty in trend (%)	Tier 1	Tier 2		Tier 1 (i. L.)	Tier 1 (i. L.)	Tier 2 (e. L.)	Tier 1	Tier 1	Tier 1
CO_2				±2.5 % points					
CH_4				±10.1% points					
N_2O				±15% points					
F-gases				±65% points					
Total	2.3%	2.3%	1990-2005: 3.4% 1990-2006: 2.5%	2.6% points	16.7%	0/20%	i. L.: 4.5% e. L.: 3.1%		i. L.: 11.6% e. L.: 11%

Table 2: continued.

Member State	Ireland	Italy	Luxem-bourg	Nether-lands	Portugal	Spain	Sweden	United Kingdom	
Citation	Uncertainty Table + NIR Apr 2008, pp. 16-22	NIR May 2008, pp.32-33	Uncertainty table	NIR Apr 2008 p. 33-37 + Uncertainty Table	NIR Apr 2008, pp.13-15	NIR Apr 2008, Sec. 1.7	NIR Apr 2008, p.35-37	NIR Apr 2008 pp. 65-66 + Uncertainty Table	
Method used	Tier 1	Tier1	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 I)	Yes	Yes	No	Yes: Table A7.1 and A7.2	Annex 2	Yes, Annex 7	
Years and sectors included	emissions: 2006; trend: 1990-2006; all categories	emissions: 2006; trend: BY-2006; all categories	emissions: 2006, trend: BY-2006; allmost all categories	emissions: 2006; trend: 1990-2006; all categories	emissions and trends : BY-2006; all categories (i.L.)	emissios: 2004, 2005; trend: BY-2004; BY-2005; all categories (e. L.)	emissions: 1990 and 2006; trends: 1990-2006; all categories (e.	emissions: 2006, trend: BY - 2006, 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	i. L.: 1.7% e. L.: 1.2%			i. L.: 2.5% e. L.: 2%	1990: 8.2% 2006: 4.5%	-	2.4%(1990) 2.3%(2006)		19%(1990) 2%(2006)
CH_4	i. L.: 2.1% e. L.: 2.1%			i. L.: 17% e. L.: 17%	1990: 28.3% 2006: 23.0%	-	2.8%(1990) 2.0%(2006)		26%(1990) 22%(2006)
N_2O	i. L.: 5.7; e. L.: 5.6%			i. L.: 43% e. L.: 43%	1990: 111.6% 2006: 102.0%	-	5.3 %(1990) 5.2%(2006)		173%(1990) 231%(2006)
F-gases	i. L.: 0.2% e. L.: 0.2%			i. L.: 32% e. L.: 32%	1990: ? 2006: 64.8%		0.2%(1990) 0.4%(2006)		(1990 and 2006) HFC 15% PFC 6% SF6 24%
Total	i. L.: 6.3% e. L.: 6.1%	i. L.: 8.6% e. L.: 3.2%	6.8%	i. L.: 4.3% e. L.: 4.1%	1990: 12.9% 2006: 9.9%	2004: 12.2% 2005: 10.9%	6.5%(1990) 6.0%(2006)	i. L.: 15.9% e. L.: 15.8%	15%(1990) 14%(2006)
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	i. L.: 2.1% e. L.: 1.8%			3 %points					-8.8 to -3.8
CH_4	i. L.: 1.8% e. L.: 1.8%			10 %points					-56 to -48
N_2O	i. L.: 2.5% e. L.: 2.6%			16 %points					-59 to -27
F-gases	i. L.: 0.2% e. L.: 0.2%			8 %points					HFC -34 to 0% PFC -81 to -77% SF6 -40 to -21%
Total	i. L.: 3.7% e. L.: 3.6%	i. L.: 7.9% e. L.: 2.6%	4.7%	3 %points	14.2%	BY-2004: 10.6% BY-2005: 12.3%	2.6%	i. L.: 2.7% e. L.: 2.7%	-18.3 to -13.1

Table 2: continued.

Member State	Bulgaria	Cyprus	Czech Republic	Estonia	Hungary	Latvia	Lithuania	Malta	Poland	Romania	Slovakia	Slovenia
Citation	Uncertainty Table + NIR pp. 29-34	NIR, March 2008, pp. 11-12	NIR Apr 2008 pp. 23-27 + Uncertainty Table	Annex 8, Uncertainty Analysis	NIR Apr 2008, p. 23 + Uncertainty table	NIR Apr 2008, p.18	Short NIR, Dec 2007, p. 16		Uncertainty assessment of the 2006 inventory	Uncertainty Table and Direct Communication	Uncertainty Table	NIR 2008, Apr 2008, p. 19 and Annex 7
Method used	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		No	Yes	Yes (extra table)	Yes	Yes: Annex 2 for 2004 (?)		Yes	Yes	Yes	Yes
Years and sectors included	emissions: 2006; BY-2006; all categories (e. L.)	emissions: 1990-2006; trends: 1990-2006; most categories (with LULUCF)	emissions: 2006; trend: 1990- 2006; all categories (e. L.)	emissions: 1990; all categories	emissions: 2006; trend: BY-2006; all categories (e. L)	emissions: 2006; trend: 1990-2006; almost all categories (e. L.)	emissions: 2006; trends: BY-2006, allmost all categories (e. L.)	no uncer-tainty assessment	emissions: 2006 ; all sources	emissions: 2006; trend: 1989 to 2006; all categories	emissions 1990 and 2006; trend: 1990-2006; almost all categories	emissions: 1986, 2006; trend: 1968-2006; all categories
Uncertainty (%)	Tier 1	Tier 1	Tier 1	Tier 1	Tier 1		Tier 1		Tier 1	Tier 1	Tier 1 (i. L.)	Tier 1
CO_2					2-4%	3.5%	1.7%		8.0%			
CH_4					15-25%	17%	3%		20.1%			
N_2O					80-90%	28%	7.7%		47.7%			
F-gases									HFC 43.7% PFC 20% SF6 100%			
Total	13.3%	1990: 14.1% 2005: 13% 2006: 1.4%	6.2%	i. L.: 44.4%; e. L.: 6.5%	5%	5%	8.4%			e. L.: 18.1% i. L.: 33.5%	1990: 16.2%; 2006: 12.7%	e. L.: 8.9% (1986) and 7.0% (2006); i. L.: 9.9% (1986) and 11.3% (2006)
Uncertainty in trend (%)	Tier 1		Tier 1		Tier 1					Tier 1	Tier 1 (i. L.)	Tier 1
CO_2		2005: 6.9% 2006: 6.5%				1.5%						
CH_4		2005: 1.7% 2006: 6.5%				7%						
N_2O		2005: 16.1% 2006: 6.5%				14%						
F-gases		HFC´s 2005: 0.5% 2006:6.5%										
Total	3.9%	1990: 21.1% 2005: 49% 2006: 76.2%	3.1%		2.4%	2.3%	1.9%			e. L.: 4.4%; i. L.: 11.5%	7.8%	6%

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):

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

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 Fig. 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).

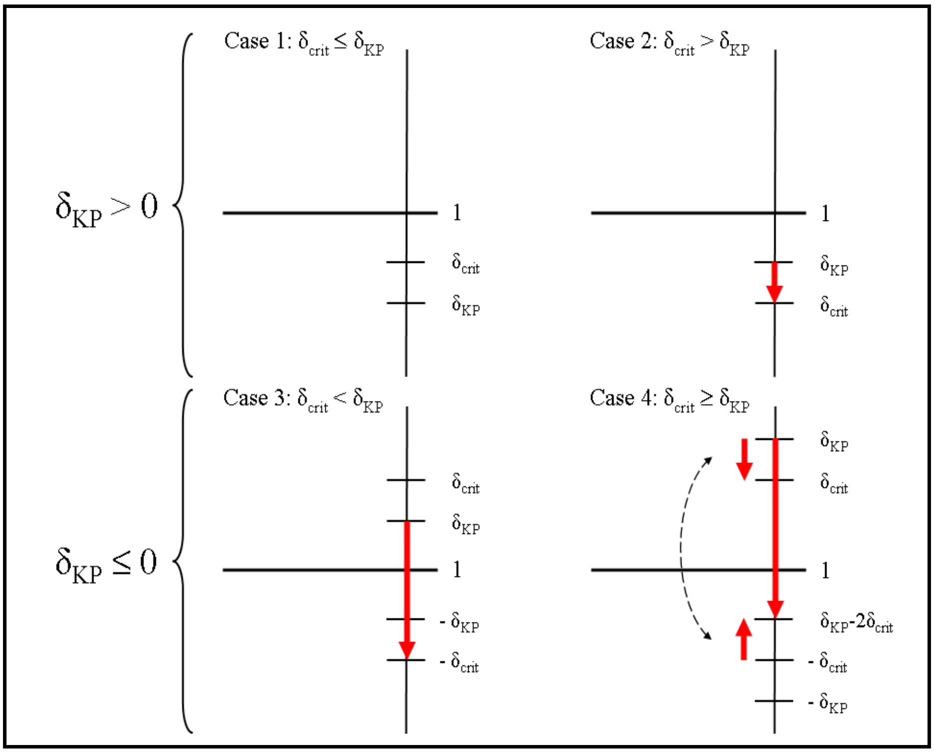

Figure 4: The four cases that are distinguished in applying the Und&VT concept (see also Tab. 3). Emission reduction: $\delta_{KP} > 0$; emission limitation: $\delta_{KP} \leq 0$.

<u>Case 1</u>: $\delta_{KP} > 0 : \delta_{crit} \leq \delta_{KP}$. 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):

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

where

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

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

<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):

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

where

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

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

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

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

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

with

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

Case 4: $\delta_{KP} \le 0 : \delta_{crit} \ge \delta_{KP}$. 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]

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

where

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

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

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 Tab. 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 Tab. 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 2nd step of the evaluation where the focus is on the Member States' emissions as of 2006.

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. Tab. 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 $(-16/20)$. 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 $(-16/20)$ establishes the linear path (base year–commitment year) emission targets and undershooting opportunities for the year 2006 (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 Tab. 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	Modified Emission Limitation or Reduction Target δ_{mod} in % for $\rho =$								
	%	1	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 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
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 $(-16/20)$ 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 2006.

MS	δ_{KP_06}	α	Undershooting U in % for $\rho =$								
	%	**1**	**0%**	**2.5%**	**5%**	**7.5%**	**10%**	**15%**	**20%**	**30%**	**40%**
AT	**-10.4**	0.0	0,0	-1,7	-3,3	-4,9	-6,3	-9,1	-14,0	-22,3	-28,8
		0.1	0,0	-1,4	-2,7	-3,9	-5,2	-7,5	-12,1	-20,0	-26,3
		0.2	0,0	-1,0	-2,0	-3,0	-3,9	-5,8	-10,1	-17,4	-23,5
		0.3	0,0	-0,7	-1,4	-2,0	-2,7	-4,0	-7,9	-14,7	-20,3
		0.4	0,0	-0,3	-0,7	-1,0	-1,4	-2,1	-5,5	-11,5	-16,7
		0.5	0,0	0,0	0,0	0,0	0,0	0,0	-2,9	-8,1	-12,5
BE	**-6.0**	0.0	0,0	-1,8	-3,5	-5,2	-7,9	-13,5	-18,4	-26,7	-33,2
		0.1	0,0	-1,5	-2,8	-4,2	-6,7	-11,9	-16,5	-24,4	-30,7
		0.2	0,0	-1,1	-2,2	-3,2	-5,4	-10,2	-14,5	-21,8	-27,9
		0.3	0,0	-0,7	-1,5	-2,2	-4,1	-8,4	-12,3	-19,1	-24,7
		0.4	0,0	-0,4	-0,7	-1,1	-2,7	-6,5	-9,9	-15,9	-21,1
		0.5	0,0	0,0	0,0	0,0	-1,3	-4,4	-7,3	-12,5	-16,9
BG	**-6.4**	0.0	0,0	-1,8	-3,5	-5,1	-7,5	-13,1	-18,0	-26,3	-32,8
		0.1	0,0	-1,4	-2,8	-4,2	-6,3	-11,5	-16,1	-24,0	-30,3
		0.2	0,0	-1,1	-2,1	-3,2	-5,0	-9,8	-14,1	-21,4	-27,5
		0.3	0,0	-0,7	-1,4	-2,1	-3,7	-8,0	-11,9	-18,7	-24,3
		0.4	0,0	-0,4	-0,7	-1,1	-2,3	-6,1	-9,5	-15,5	-20,7
		0.5	0,0	0,0	0,0	0,0	-0,9	-4,0	-6,9	-12,1	-16,5
CZ	**-6.4**	0.0	0,0	-1,8	-3,5	-5,1	-7,5	-13,1	-18,0	-26,3	-32,8
		0.1	0,0	-1,4	-2,8	-4,2	-6,3	-11,5	-16,1	-24,0	-30,3
		0.2	0,0	-1,1	-2,1	-3,2	-5,0	-9,8	-14,1	-21,4	-27,5
		0.3	0,0	-0,7	-1,4	-2,1	-3,7	-8,0	-11,9	-18,7	-24,3
		0.4	0,0	-0,4	-0,7	-1,1	-2,3	-6,1	-9,5	-15,5	-20,7
		0.5	0,0	0,0	0,0	0,0	-0,9	-4,0	-6,9	-12,1	-16,5
DK	**-16.8**	0.0	0,0	-1,5	-3,0	-4,4	-5,7	-8,2	-10,5	-15,9	-22,4
		0.1	0,0	-1,2	-2,4	-3,6	-4,7	-6,8	-8,7	-13,6	-19,9
		0.2	0,0	-0,9	-1,8	-2,7	-3,6	-5,2	-6,8	-11,0	-17,1
		0.3	0,0	-0,6	-1,2	-1,8	-2,4	-3,6	-4,7	-8,3	-13,9
		0.4	0,0	-0,3	-0,6	-0,9	-1,2	-1,8	-2,4	-5,1	-10,3
		0.5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	-1,7	-6,1
EE	**-6.4**	0.0	0,0	-1,8	-3,5	-5,1	-7,5	-13,1	-18,0	-26,3	-32,8
		0.1	0,0	-1,4	-2,8	-4,2	-6,3	-11,5	-16,1	-24,0	-30,3
		0.2	0,0	-1,1	-2,1	-3,2	-5,0	-9,8	-14,1	-21,4	-27,5
		0.3	0,0	-0,7	-1,4	-2,1	-3,7	-8,0	-11,9	-18,7	-24,3
		0.4	0,0	-0,4	-0,7	-1,1	-2,3	-6,1	-9,5	-15,5	-20,7
		0.5	0,0	0,0	0,0	0,0	-0,9	-4,0	-6,9	-12,1	-16,5
FI	**0.0**	0.0	0,0	-4,0	-7,8	-11,6	-15,4	-22,7	-30,0	-44,8	-61,0
		0.1	0,0	-3,6	-7,1	-10,6	-14,2	-21,2	-28,3	-43,1	-59,8
		0.2	0,0	-3,2	-6,4	-9,7	-12,9	-19,6	-26,4	-41,3	-58,5
		0.3	0,0	-2,8	-5,7	-8,6	-11,6	-17,8	-24,4	-39,2	-57,0
		0.4	0,0	-2,4	-5,0	-7,6	-10,3	-16,0	-22,3	-36,9	-55,3
		0.5	0,0	-2,1	-4,2	-6,5	-8,9	-14,1	-20,0	-34,3	-53,3
FR	**0.0**	0.0	0,0	-4,0	-7,8	-11,6	-15,4	-22,7	-30,0	-44,8	-61,0
		0.1	0,0	-3,6	-7,1	-10,6	-14,2	-21,2	-28,3	-43,1	-59,8
		0.2	0,0	-3,2	-6,4	-9,7	-12,9	-19,6	-26,4	-41,3	-58,5
		0.3	0,0	-2,8	-5,7	-8,6	-11,6	-17,8	-24,4	-39,2	-57,0
		0.4	0,0	-2,4	-5,0	-7,6	-10,3	-16,0	-22,3	-36,9	-55,3
		0.5	0,0	-2,1	-4,2	-6,5	-8,9	-14,1	-20,0	-34,3	-53,3

Table 9: continued.

DE	**-16.8**	0.0	0,0	-1,5	-3,0	-4,4	-5,7	-8,2	-10,5	-15,9	-22,4
		0.1	0,0	-1,2	-2,4	-3,6	-4,7	-6,8	-8,7	-13,6	-19,9
		0.2	0,0	-0,9	-1,8	-2,7	-3,6	-5,2	-6,8	-11,0	-17,1
		0.3	0,0	-0,6	-1,2	-1,8	-2,4	-3,6	-4,7	-8,3	-13,9
		0.4	0,0	-0,3	-0,6	-0,9	-1,2	-1,8	-2,4	-5,1	-10,3
		0.5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	-1,7	-6,1
GR	**20.0**	0.0	0,0	-6,4	-12,8	-19,0	-25,3	-37,6	-50,0	-64,8	-81,0
		0.1	0,0	-6,0	-11,9	-17,9	-23,9	-35,9	-48,3	-63,1	-79,8
		0.2	0,0	-5,5	-11,1	-16,7	-22,4	-34,2	-46,4	-61,3	-78,5
		0.3	0,0	-5,1	-10,2	-15,5	-20,9	-32,3	-44,4	-59,2	-77,0
		0.4	0,0	-4,6	-9,3	-14,3	-19,4	-30,3	-42,3	-56,9	-75,3
		0.5	0,0	-4,1	-8,4	-13,0	-17,8	-28,2	-40,0	-54,3	-73,3
HU	**-4.8**	0.0	0,0	-1,8	-3,6	-6,0	-9,1	-14,7	-19,6	-27,9	-34,4
		0.1	0,0	-1,5	-2,9	-5,0	-7,9	-13,1	-17,7	-25,6	-31,9
		0.2	0,0	-1,1	-2,2	-4,0	-6,6	-11,4	-15,7	-23,0	-29,1
		0.3	0,0	-0,7	-1,5	-2,9	-5,3	-9,6	-13,5	-20,3	-25,9
		0.4	0,0	-0,4	-0,7	-1,9	-3,9	-7,7	-11,1	-17,1	-22,3
		0.5	0,0	0,0	0,0	-0,8	-2,5	-5,6	-8,5	-13,7	-18,1
IE	**10.4**	0.0	0,0	-6,2	-12,3	-18,4	-24,4	-33,1	-40,4	-55,2	-71,4
		0.1	0,0	-5,8	-11,6	-17,4	-23,2	-31,6	-38,7	-53,5	-70,2
		0.2	0,0	-5,4	-10,8	-16,3	-21,9	-30,0	-36,8	-51,7	-68,9
		0.3	0,0	-5,0	-10,0	-15,2	-20,6	-28,2	-34,8	-49,6	-67,4
		0.4	0,0	-4,5	-9,2	-14,1	-19,2	-26,4	-32,7	-47,3	-65,7
		0.5	0,0	-4,1	-8,4	-13,0	-17,8	-24,5	-30,4	-44,7	-63,7
IT	**-5.2**	0.0	0,0	-1,8	-3,6	-5,6	-8,7	-14,3	-19,2	-27,5	-34,0
		0.1	0,0	-1,5	-2,9	-4,6	-7,5	-12,7	-17,3	-25,2	-31,5
		0.2	0,0	-1,1	-2,2	-3,6	-6,2	-11,0	-15,3	-22,6	-28,7
		0.3	0,0	-0,7	-1,5	-2,5	-4,9	-9,2	-13,1	-19,9	-25,5
		0.4	0,0	-0,4	-0,7	-1,5	-3,5	-7,3	-10,7	-16,7	-21,9
		0.5	0,0	0,0	0,0	-0,4	-2,1	-5,2	-8,1	-13,3	-17,7
LV	**-6.4**	0.0	0,0	-1,8	-3,5	-5,1	-7,5	-13,1	-18,0	-26,3	-32,8
		0.1	0,0	-1,4	-2,8	-4,2	-6,3	-11,5	-16,1	-24,0	-30,3
		0.2	0,0	-1,1	-2,1	-3,2	-5,0	-9,8	-14,1	-21,4	-27,5
		0.3	0,0	-0,7	-1,4	-2,1	-3,7	-8,0	-11,9	-18,7	-24,3
		0.4	0,0	-0,4	-0,7	-1,1	-2,3	-6,1	-9,5	-15,5	-20,7
		0.5	0,0	0,0	0,0	0,0	-0,9	-4,0	-6,9	-12,1	-16,5
LT	**-6.4**	0.0	0,0	-1,8	-3,5	-5,1	-7,5	-13,1	-18,0	-26,3	-32,8
		0.1	0,0	-1,4	-2,8	-4,2	-6,3	-11,5	-16,1	-24,0	-30,3
		0.2	0,0	-1,1	-2,1	-3,2	-5,0	-9,8	-14,1	-21,4	-27,5
		0.3	0,0	-0,7	-1,4	-2,1	-3,7	-8,0	-11,9	-18,7	-24,3
		0.4	0,0	-0,4	-0,7	-1,1	-2,3	-6,1	-9,5	-15,5	-20,7
		0.5	0,0	0,0	0,0	0,0	-0,9	-4,0	-6,9	-12,1	-16,5
LU	**-22.4**	0.0	0,0	-1,4	-2,7	-4,0	-5,2	-7,5	-9,6	-13,3	-16,8
		0.1	0,0	-1,1	-2,2	-3,3	-4,3	-6,2	-7,9	-11,1	-14,3
		0.2	0,0	-0,9	-1,7	-2,5	-3,3	-4,8	-6,2	-8,8	-11,5
		0.3	0,0	-0,6	-1,1	-1,7	-2,2	-3,3	-4,3	-6,2	-8,3
		0.4	0,0	-0,3	-0,6	-0,9	-1,1	-1,7	-2,2	-3,3	-4,7
		0.5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	-0,5
NL	**-4.8**	0.0	0,0	-1,8	-3,6	-6,0	-9,1	-14,7	-19,6	-27,9	-34,4
		0.1	0,0	-1,5	-2,9	-5,0	-7,9	-13,1	-17,7	-25,6	-31,9
		0.2	0,0	-1,1	-2,2	-4,0	-6,6	-11,4	-15,7	-23,0	-29,1
		0.3	0,0	-0,7	-1,5	-2,9	-5,3	-9,6	-13,5	-20,3	-25,9
		0.4	0,0	-0,4	-0,7	-1,9	-3,9	-7,7	-11,1	-17,1	-22,3
		0.5	0,0	0,0	0,0	-0,8	-2,5	-5,6	-8,5	-13,7	-18,1

Table 9: continued.

PL	**-4.8**	0.0	0,0	-1,8	-3,6	-6,0	-9,1	-14,7	-19,6	-27,9	-34,4
		0.1	0,0	-1,5	-2,9	-5,0	-7,9	-13,1	-17,7	-25,6	-31,9
		0.2	0,0	-1,1	-2,2	-4,0	-6,6	-11,4	-15,7	-23,0	-29,1
		0.3	0,0	-0,7	-1,5	-2,9	-5,3	-9,6	-13,5	-20,3	-25,9
		0.4	0,0	-0,4	-0,7	-1,9	-3,9	-7,7	-11,1	-17,1	-22,3
		0.5	0,0	0,0	0,0	-0,8	-2,5	-5,6	-8,5	-13,7	-18,1
PT	**21.6**	0.0	0,0	-6,5	-12,9	-19,2	-25,4	-37,8	-50,3	-66,4	-82,6
		0.1	0,0	-6,0	-12,0	-18,0	-24,0	-36,1	-48,5	-64,7	-81,4
		0.2	0,0	-5,5	-11,1	-16,8	-22,5	-34,3	-46,6	-62,9	-80,1
		0.3	0,0	-5,1	-10,2	-15,6	-21,0	-32,4	-44,6	-60,8	-78,6
		0.4	0,0	-4,6	-9,3	-14,3	-19,4	-30,4	-42,4	-58,5	-76,9
		0.5	0,0	-4,1	-8,4	-13,0	-17,8	-28,2	-40,0	-55,9	-74,9
RO	**-6.4**	0.0	0,0	-1,8	-3,5	-5,1	-7,5	-13,1	-18,0	-26,3	-32,8
		0.1	0,0	-1,4	-2,8	-4,2	-6,3	-11,5	-16,1	-24,0	-30,3
		0.2	0,0	-1,1	-2,1	-3,2	-5,0	-9,8	-14,1	-21,4	-27,5
		0.3	0,0	-0,7	-1,4	-2,1	-3,7	-8,0	-11,9	-18,7	-24,3
		0.4	0,0	-0,4	-0,7	-1,1	-2,3	-6,1	-9,5	-15,5	-20,7
		0.5	0,0	0,0	0,0	0,0	-0,9	-4,0	-6,9	-12,1	-16,5
SK	**-6.4**	0.0	0,0	-1,8	-3,5	-5,1	-7,5	-13,1	-18,0	-26,3	-32,8
		0.1	0,0	-1,4	-2,8	-4,2	-6,3	-11,5	-16,1	-24,0	-30,3
		0.2	0,0	-1,1	-2,1	-3,2	-5,0	-9,8	-14,1	-21,4	-27,5
		0.3	0,0	-0,7	-1,4	-2,1	-3,7	-8,0	-11,9	-18,7	-24,3
		0.4	0,0	-0,4	-0,7	-1,1	-2,3	-6,1	-9,5	-15,5	-20,7
		0.5	0,0	0,0	0,0	0,0	-0,9	-4,0	-6,9	-12,1	-16,5
SI	**-6.4**	0.0	0,0	-1,8	-3,5	-5,1	-7,5	-13,1	-18,0	-26,3	-32,8
		0.1	0,0	-1,4	-2,8	-4,2	-6,3	-11,5	-16,1	-24,0	-30,3
		0.2	0,0	-1,1	-2,1	-3,2	-5,0	-9,8	-14,1	-21,4	-27,5
		0.3	0,0	-0,7	-1,4	-2,1	-3,7	-8,0	-11,9	-18,7	-24,3
		0.4	0,0	-0,4	-0,7	-1,1	-2,3	-6,1	-9,5	-15,5	-20,7
		0.5	0,0	0,0	0,0	0,0	-0,9	-4,0	-6,9	-12,1	-16,5
ES	**12.0**	0.0	0,0	-6,2	-12,4	-18,5	-24,5	-34,7	-42,0	-56,8	-73,0
		0.1	0,0	-5,8	-11,6	-17,4	-23,3	-33,2	-40,3	-55,1	-71,8
		0.2	0,0	-5,4	-10,9	-16,4	-22,0	-31,6	-38,4	-53,3	-70,5
		0.3	0,0	-5,0	-10,1	-15,3	-20,6	-29,8	-36,4	-51,2	-69,0
		0.4	0,0	-4,5	-9,2	-14,1	-19,2	-28,0	-34,3	-48,9	-67,3
		0.5	0,0	-4,1	-8,4	-13,0	-17,8	-26,1	-32,0	-46,3	-65,3
SE	**3.2**	0.0	0,0	-6,0	-11,0	-14,8	-18,6	-25,9	-33,2	-48,0	-64,2
		0.1	0,0	-5,7	-10,3	-13,8	-17,4	-24,4	-31,5	-46,3	-63,0
		0.2	0,0	-5,3	-9,6	-12,9	-16,1	-22,8	-29,6	-44,5	-61,7
		0.3	0,0	-4,9	-8,9	-11,8	-14,8	-21,0	-27,6	-42,4	-60,2
		0.4	0,0	-4,5	-8,2	-10,8	-13,5	-19,2	-25,5	-40,1	-58,5
		0.5	0,0	-4,1	-7,4	-9,7	-12,1	-17,3	-23,2	-37,5	-56,5
UK	**-10.0**	0.0	0,0	-1,7	-3,3	-4,9	-6,4	-9,5	-14,4	-22,7	-29,2
		0.1	0,0	-1,4	-2,7	-4,0	-5,2	-7,9	-12,5	-20,4	-26,7
		0.2	0,0	-1,0	-2,0	-3,0	-4,0	-6,2	-10,5	-17,8	-23,9
		0.3	0,0	-0,7	-1,4	-2,0	-2,7	-4,4	-8,3	-15,1	-20,7
		0.4	0,0	-0,3	-0,7	-1,0	-1,4	-2,5	-5,9	-11,9	-17,1
		0.5	0,0	0,0	0,0	0,0	0,0	-0,4	-3,3	-8,5	-12,9
EU-15	**-6.4**	0.0	0,0	-1,8	-3,5	-5,1	-7,5	-13,1	-18,0	-26,3	-32,8
		0.1	0,0	-1,4	-2,8	-4,2	-6,3	-11,5	-16,1	-24,0	-30,3
		0.2	0,0	-1,1	-2,1	-3,2	-5,0	-9,8	-14,1	-21,4	-27,5
		0.3	0,0	-0,7	-1,4	-2,1	-3,7	-8,0	-11,9	-18,7	-24,3
		0.4	0,0	-0,4	-0,7	-1,1	-2,3	-6,1	-9,5	-15,5	-20,7
		0.5	0,0	0,0	0,0	0,0	-0,9	-4,0	-6,9	-12,1	-16,5

4 Interpretation of Results and Conclusions

To interpret the results for 2006, 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 2006 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 $(-16/20)$). 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 13 countries that exhibit a negative DTPI: BG, CZ, DE, EE, FR, HU, LT, LV, PL, RO, SE, SK and the UK; BE's DTPI, slightly negative, is considered zero (cf. Fig. 2). Given $\alpha = 0.5$, EE, LV, LT, BG, RO, SK, HU, PL and the CZ are the best potential sellers followed by DE, the UK, SE and FR (Fig. 5). EE, LV, LT, BG, RO, SK, HU, PL and the CZ can report with a relative uncertainty > 40% and still exhibit a detectable signal (see Tab. A1 for exact numbers); while DE and the UK must report within the 20–40% relative uncertainty class (more exactly: up to 30% and 25%, respectively), SE within the 5–10% relative uncertainty (more exactly: up to 10%), and FR within 0–5% relative uncertainty class (more exactly: up to 4.8%).

Figures 6–10 display U by ρ for $\alpha = 0.0,\ldots,0.5$. These figures can be interpreted similarly to Figure 5, bearing in mind that U increases in absolute terms with decreasing α. For $\alpha = 0.0$ (Fig. 10), EE, LV, LT, BG and RO can still report with a relative uncertainty > 40% (see Tab. A1 for exact numbers); while SK, HU and PL must report within the 20–40% relative uncertainty class (more exactly: up to 29%, 29% and 25%, respectively); the CZ within the 10–20% relative uncertainty class (more exactly: up to 19%); the UK and SE within the 5–10% relative uncertainty class (more exactly: up to 9% and 6%, respectively); and DE and FR within the 0–5% relative uncertainty class (more exactly: up to 2.7 and 2.5%, 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 $(-16/20)$ 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 detection 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 2006. 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 2006 thirteen EU-27 Member States exhibit a negative DTPI and thus appear as potential sellers: BG, CZ, DE, EE, FR, HU, LT, LV, PL, RO, SE, SK and the UK; BE's DTPI, slightly negative, is considered zero (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 twenty-six of the 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 (Fig. 9: ranked in terms of credibility) are EE, LV, LT, BG and RO which can report with a relative uncertainty > 40% and still exhibit a detectable signal; while SK, HU, PL and the CZ, and the UK can still report within the 20–40% and 10–20% relative uncertainty class, respectively. In contrast, DE, SE and FR can only act as potential sellers with a higher risk: DE and SE only with $\alpha \approx 0.35$ within the upper part of the 5–10% relative uncertainty class (Fig. 6, 7); 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 2006, 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 $U_{Gap} < \text{DTPI}$), 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.

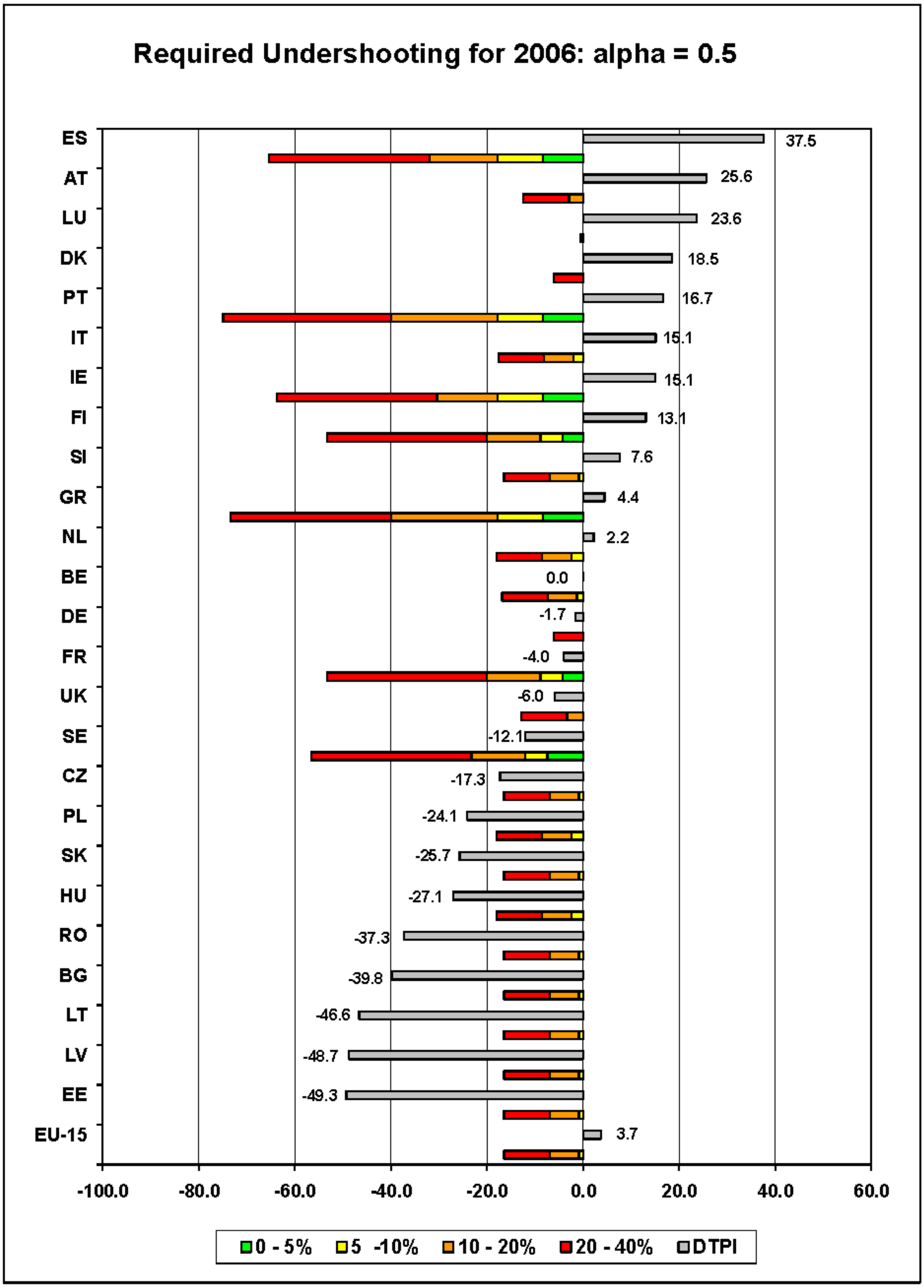

Figure 5: U by ρ (see intervals) for $\alpha = 0.5$ in addition to the DTPI.

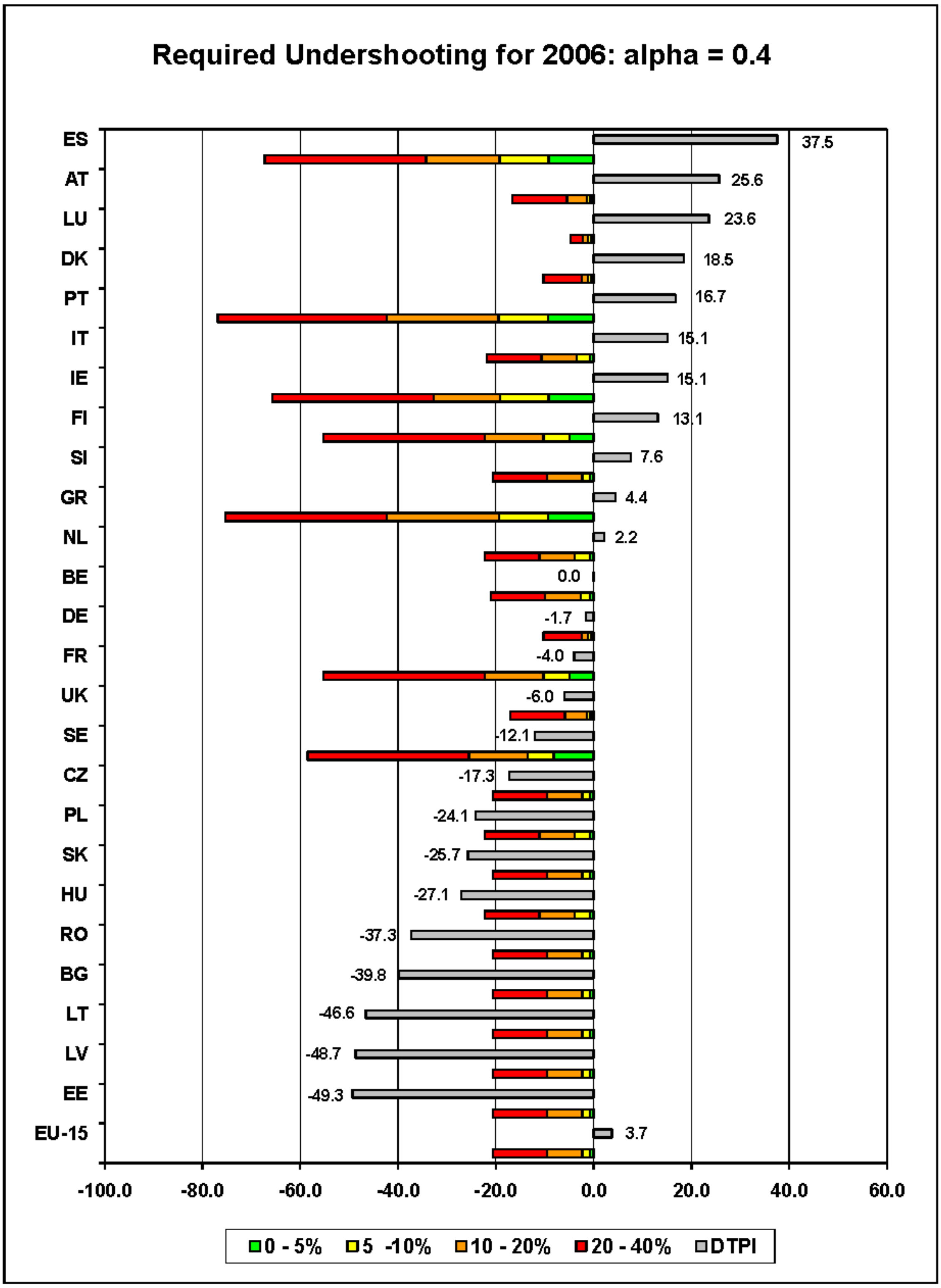

Figure 6: U by ρ (see intervals) for $\alpha = 0.4$ in addition to the DTPI.

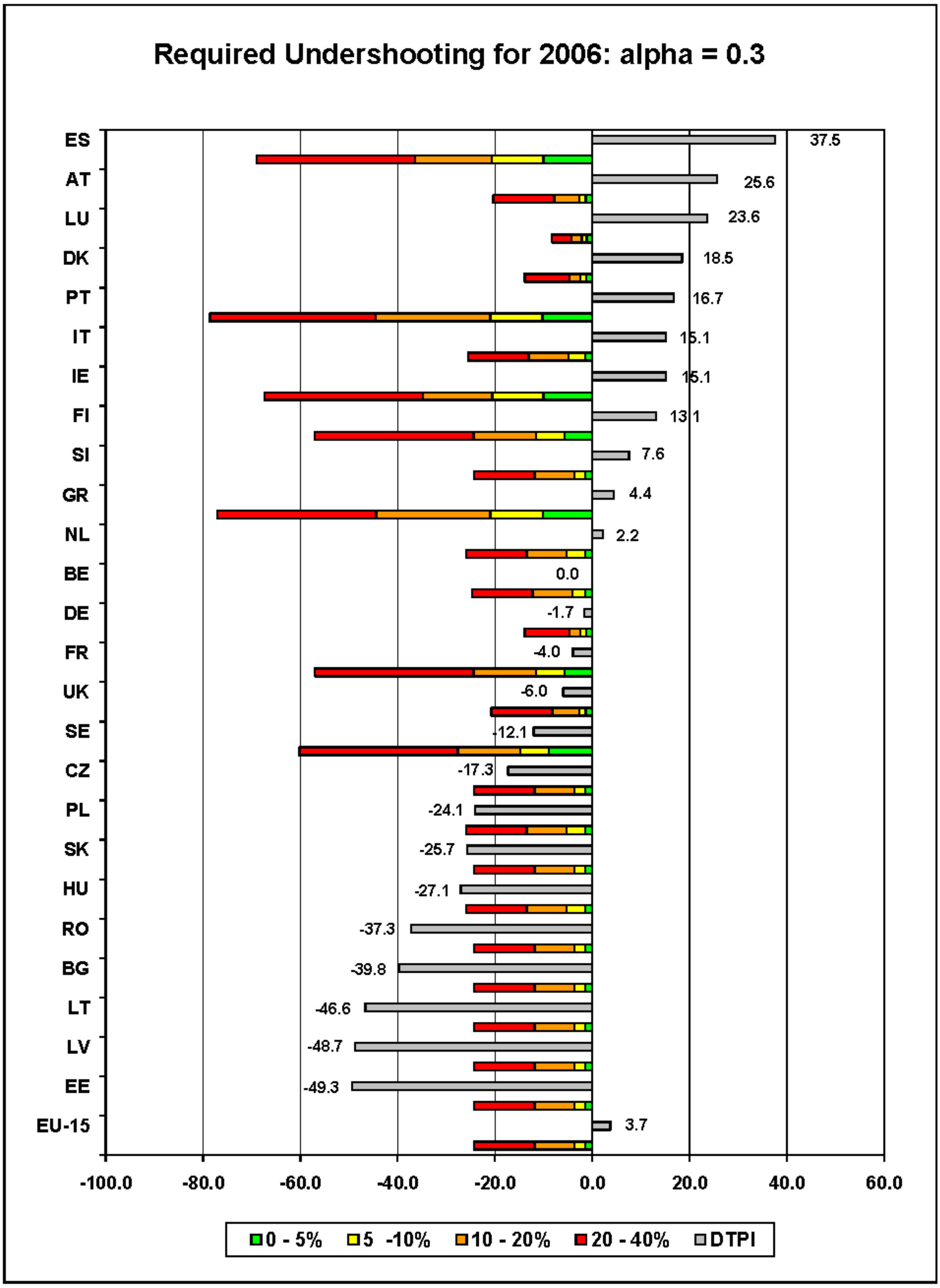

Figure 7: U by ρ (see intervals) for $\alpha = 0.3$ in addition to the DTPI.

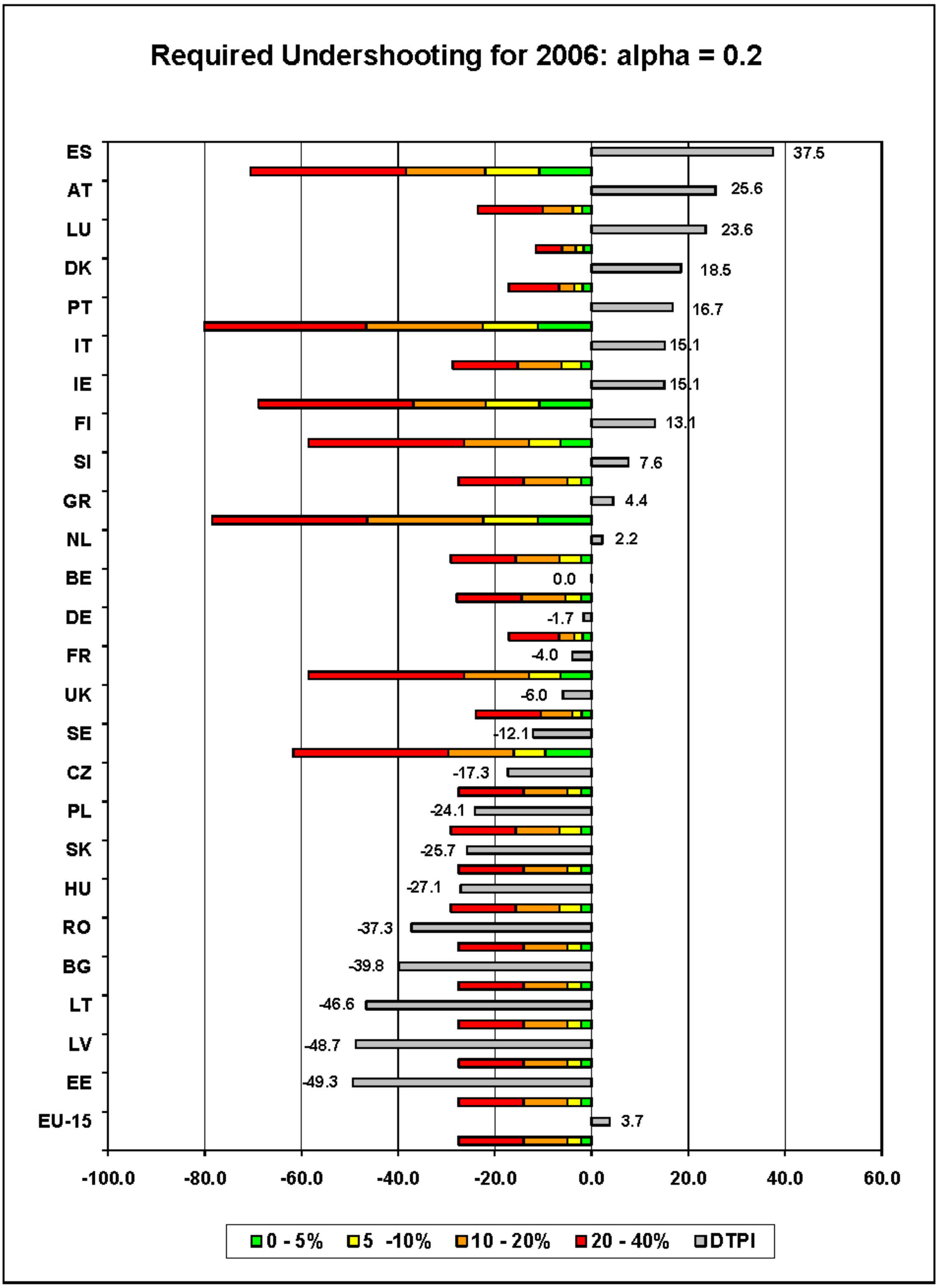

Figure 8: U by ρ (see intervals) for $\alpha = 0.2$ in addition to the DTPI.

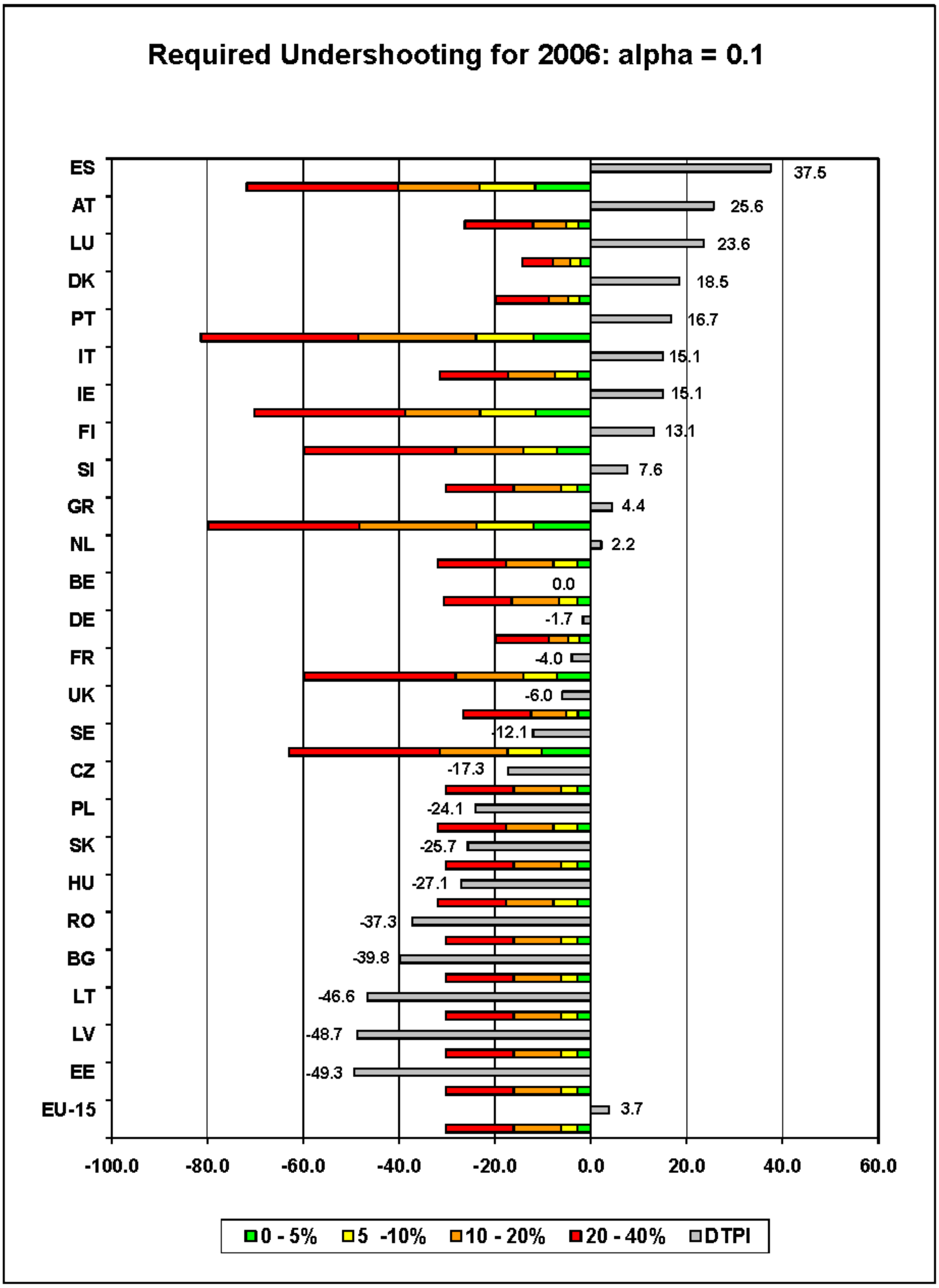

Figure 9: U by ρ (see intervals) for $\alpha = 0.1$ in addition to the DTPI.

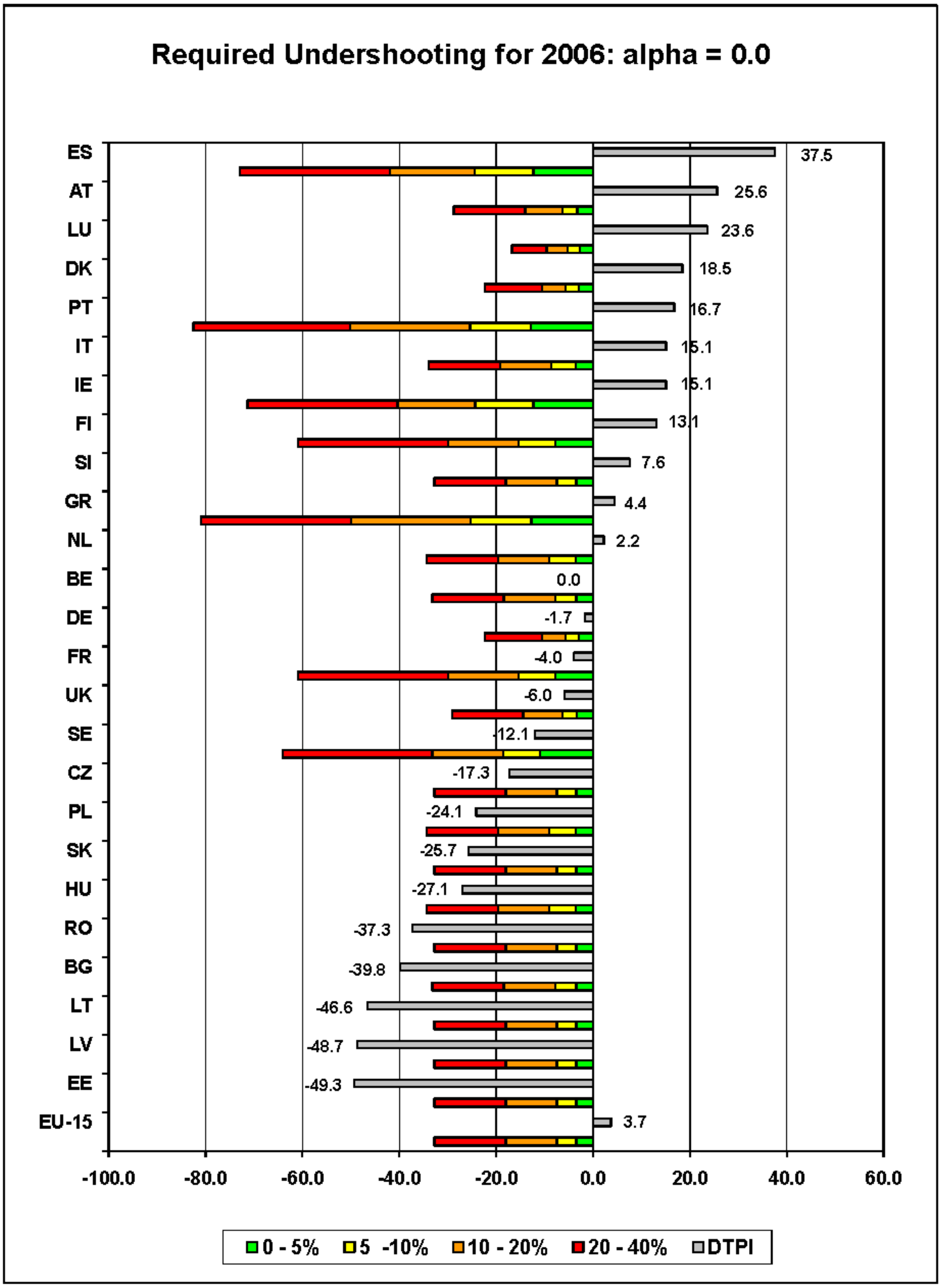

Figure 10: U by ρ (see intervals) for $\alpha = 0.0$ in addition to the DTPI.

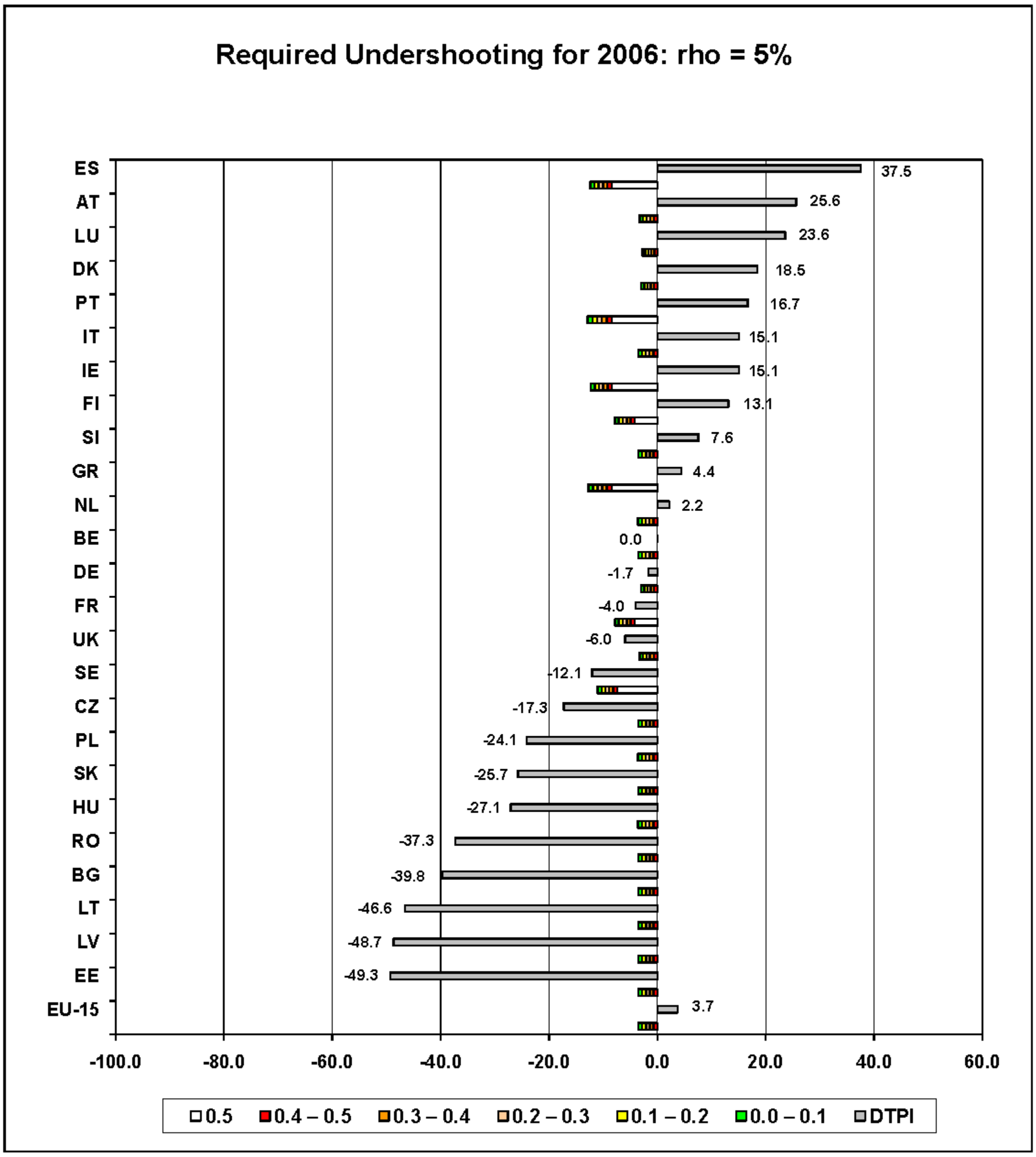

Figure 11: U by α (see value and intervals) for $\rho = 5\%$ in addition to the DTPI.

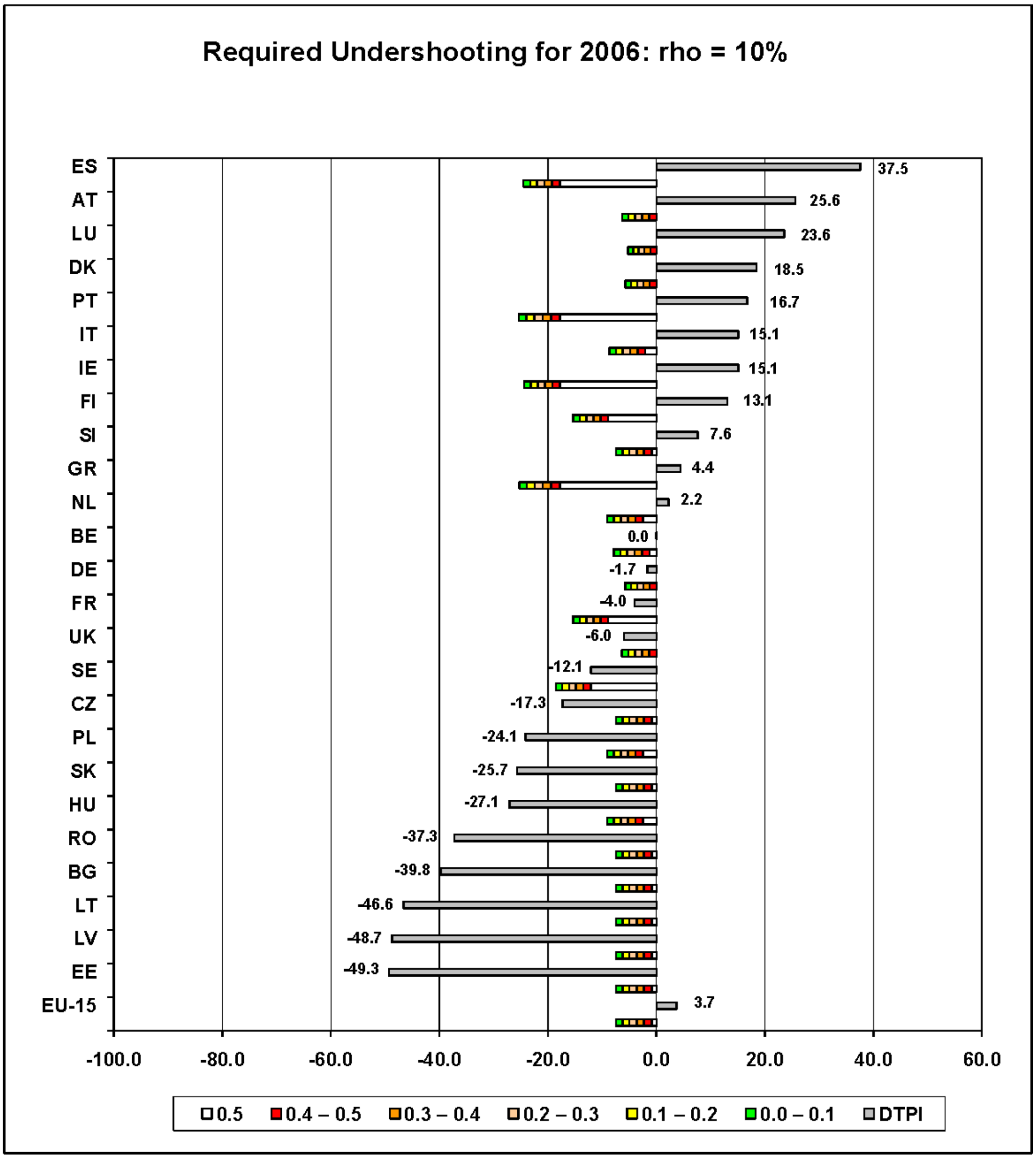

Figure 12: U by α (see value and intervals) for $\rho = 10\%$ in addition to the DTPI.

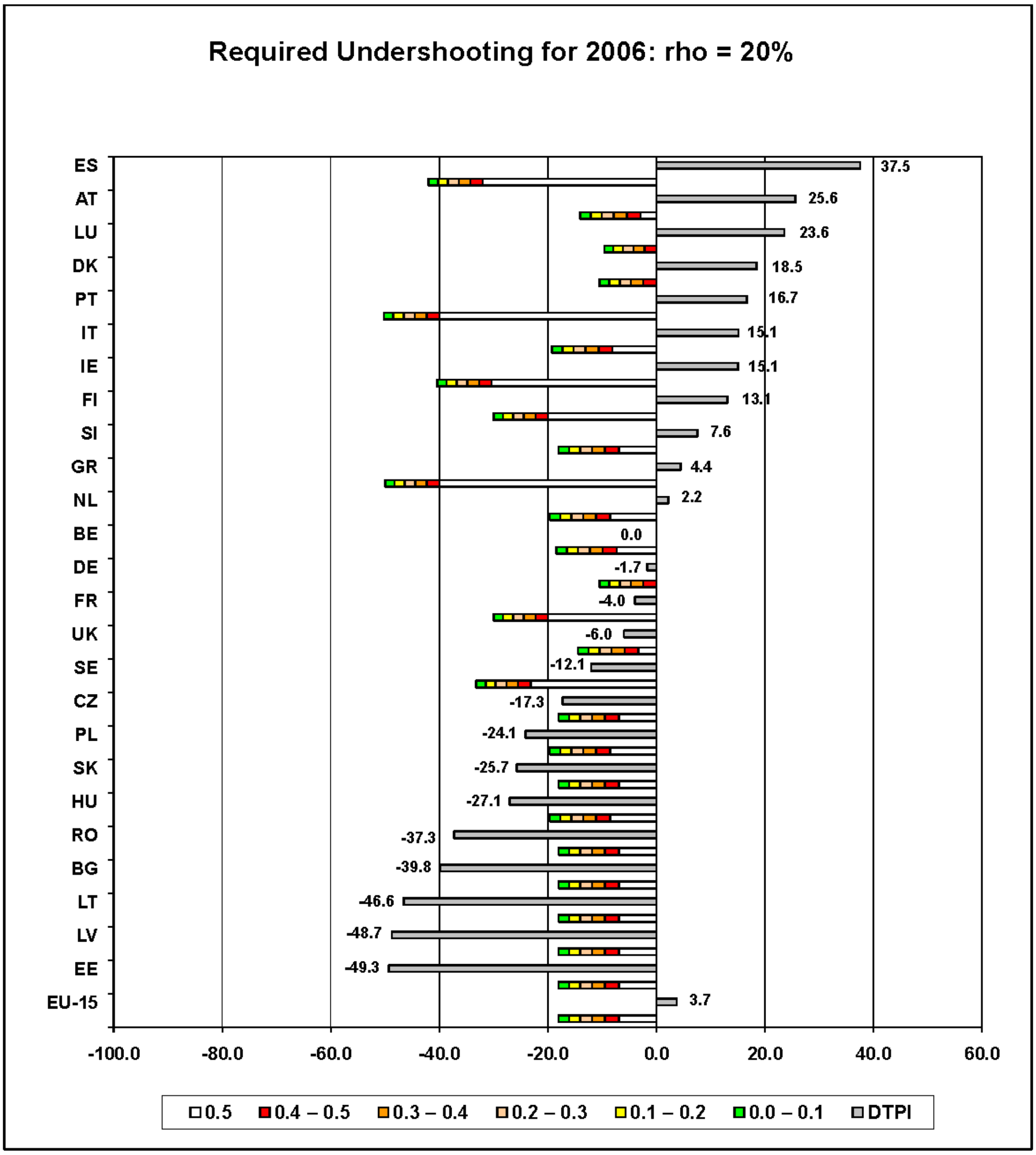

Figure 13: U by α (see value and intervals) for $\rho = 20\%$ in addition to the DTPI.

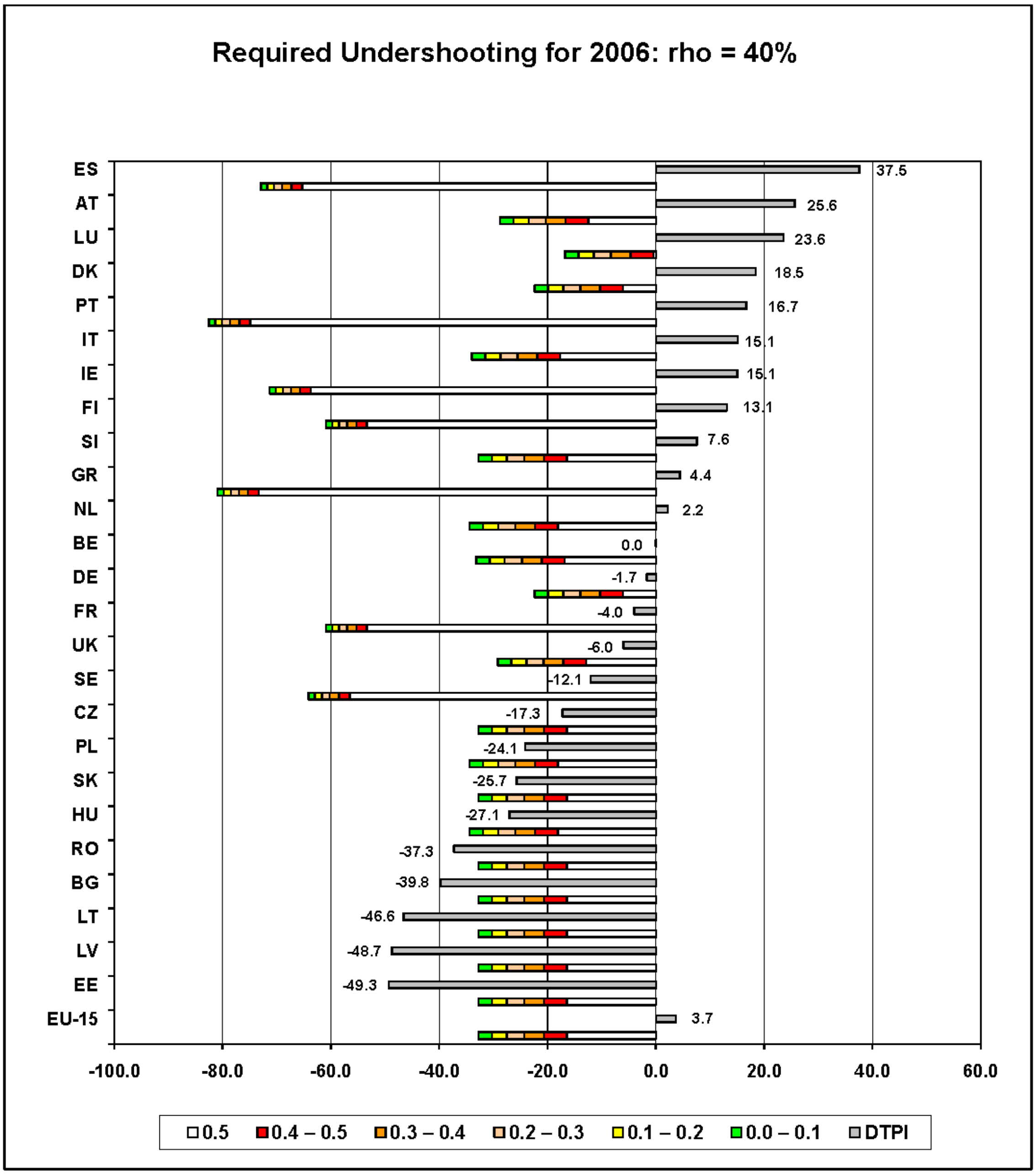

Figure 14: U by α (see value and intervals) for $\rho = 40\%$ in addition to the DTPI.

References

EEA (2008a). Annual European Community Greenhouse Gas Inventory 1990–2006 and Inventory Report 2008. Technical Report No. 6, European Environment Agency (EEA), Copenhagen, Denmark, pp. 587, ISBN: 978-92-9167-361-2, DOI: 10.2800/39030. Available at: http://www.eea.europa.eu/publications/technical_report_2008_6.

EEA (2008b). Greenhouse Gas Emission Trends and Projections in Europe 2008. Report No. 5, European Environment Agency (EEA), Copenhagen, Denmark, pp. 178, ISBN: 978-92-9167-981-2, DOI: 10.2800/10716. Available at: http://www.eea.europa.eu/publications/eea_report_2008_5.

EU Official Journal (2002). Council Decision as 25 April 2002. OJ L 130, 15 May 2002, pp. 20. Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2002:130:0001:0020:EN:PDF.

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

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

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

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

Jonas, M., M. Gusti, W. Jęda, Z. Nahorski and S. Nilsson, 2010: Comparison of preparatory signal analysis techniques for consideration in the (post-) Kyoto policy process. *Clim. Change*, **103**(1–2), 175–213, doi: 10.1007/s10584-010-9914-6.

Supporting online material (SOM):

(1) Mathematical background and numerical tables (pp. 26; Doc file); (2) Numerical results (Excel file). International Institute for Applied Systems Analysis, Laxenburg, Austria. Available at: http://www.iiasa.ac.at/Research/FOR/unc_prep.html.

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

Overview of Background and Monitoring Reports

Annex B Countries under the Kyoto Protocol: 1990–2008/12

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

Jonas, M., M. Gusti, W. Jęda, Z. Nahorski and S. Nilsson, 2010: Comparison of preparatory signal analysis techniques for consideration in the (post-) Kyoto policy process. *Clim. Change*, **103**(1–2), 175–213, doi: 10.1007/s10584-010-9914-6.

Supporting online material:

(1) Mathematical background and numerical tables (pp. 26; Doc file); (2) Numerical results (Excel file). International Institute for Applied Systems Analysis, Laxenburg, Austria. Available at: http://www.iiasa.ac.at/Research/FOR/unc_prep.html.

EU-15 Member States under EU Burden Sharing: From 1990–2001 to 1990–2003

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

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

Bun, A. and M. Jonas, 2007: Preparatory Signal Detection for the EU-15 Member States Under EU Burden Sharing—Advanced Monitoring Including Uncertainty (1990–2003). Interim Report IR-06-053, International Institute for Applied Systems Analysis, Laxenburg, Austria, pp. 30. Available at: http://www.iiasa.ac.at/Publications/Documents/IR-06-053.pdf.

EU-25 Member States under EU Burden Sharing: From 1990–2003 to 1990–2004

Bun, A. and M. Jonas, 2007: Preparatory Signal Detection for the EU-25 Member States Under EU Burden Sharing—Advanced Monitoring Including Uncertainty (1990–2003). Interim Report IR-06-054, International Institute for Applied Systems Analysis, Laxenburg, Austria, pp. 39. Available at: http://www.iiasa.ac.at/Publications/Documents/IR-06-054.pdf.

Hamal, K. and M. Jonas, 2008: Preparatory Signal Detection for the EU-25 Member States Under EU Burden Sharing—Advanced Monitoring Including Uncertainty (1990–2004). Interim Report IR-08-036, International Institute for Applied Systems Analysis, Laxenburg, Austria, pp. 40. Available at: http://www.iiasa.ac.at/Publications/Documents/IR-08-036.pdf.

EU-27 Member States under EU Burden Sharing: 1990–2005

Hamal, K. and M. Jonas (2008). Preparatory Signal Detection for the EU-27 Member States Under EU Burden Sharing—Advanced Monitoring Including Uncertainty (1990–2005). Interim Report IR-08-037, International Institute for Applied Systems Analysis, Laxenburg, Austria, pp. 46. Available at: http://www.iiasa.ac.at/Publications/Documents/IR-08-037.pdf.

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.

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

<u>$\alpha = 0.5$:</u>

$U = 0$ for all ρ. (A1)

<u>$0 \le \alpha < 0.5$:</u>

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

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

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

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:

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

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

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

<u>$\alpha = 0.5$:</u>

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

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

$$\frac{\rho}{1+\rho} = \delta_{mod} \quad \text{(A7)}$$

$$\rho = \frac{\delta_{mod}}{1-\delta_{mod}}. \quad \text{(A8)}$$

0 ≤ α < 0.5:

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

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

In combination with Eq. (1a):

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

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

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

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

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

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

Eq. (A12a) provides the correct solution.

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

α = 0.5:

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

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

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

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

<u>*0 ≤ α < 0.5:*</u>

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

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

In combination with Eq. (1b):

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

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

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

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

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

Eq. (A21b) provides the correct solution.

<u>*Case 4*</u>: $\delta_{KP} \le 0 : \delta_{crit} \ge \delta_{KP}$. Eq. (17) in combination with Eq. (18) and (19) for $\alpha = 0.5$ and $0 \le \alpha < 0.5$:

<u>*α = 0.5:*</u>

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

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

$$\rho = \frac{U}{2+U}. \qquad \text{(A23)}$$

0 ≤ α < 0.5:

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

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

In combination with Eq. (1b):

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

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

$$KT - (2+KT)\rho = KT_{mod} + (1-2\alpha)KT_{mod}\rho - KT_{mod}\rho - (1-2\alpha)KT_{mod}\rho^2 \qquad \text{(A27)}$$

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

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

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 $0 \le \alpha \le 0.5$ 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 2006 must be multiplied with (-20/16). Example: To meet $\alpha = 0.1$, the CZ can report with an uncertainty ρ of 21.4% owing to its DTPI of -17.3% (or 21.6% if multiplied with (-20/16); see Fig. 9).

MS	δ_{KP} **%**	α **1**	**DTPI 1**	ρ **1**	**Case**	**Eq.**
BE	**7.5**	0.0	0.0001	0.0001	Case 1	(A4)
		0.1	0.0001	0.0002	Case 1	(A4)
		0.2	0.0001	0.0002	Case 1	(A4)
		0.3	0.0001	0.0003	Case 1	(A4)
		0.4	0.0001	0.0007	Case 1	(A4)
		0.5	0.0001	0.081	Case 2	(A8)
BG	**8.0**	0.0	0,498	0,539	Case 2	(A12a)
		0.1	0,498	0,600	Case 2	(A12a)
		0.2	0,498	0,681	Case 2	(A12a)
		0.3	0,498	0,796	Case 2	(A12a)
		0.4	0,498	0,979	Case 2	(A12a)
		0.5	0,498	>1	Case 2	(A8)
CZ	**8.0**	0.0	0,216	0,192	Case 2	(A12a)
		0.1	0,216	0,214	Case 2	(A12a)
		0.2	0,216	0,241	Case 2	(A12a)
		0.3	0,216	0,279	Case 2	(A12a)
		0.4	0,216	0,332	Case 2	(A12a)
		0.5	0,216	0,421	Case 2	(A8)
EE	**8.0**	0.0	0,616	0,815	Case 2	(A12a)
		0.1	0,616	0,908	Case 2	(A12a)
		0.2	0,616	>1	Case 2	(A12a)
		0.3	0,616	>1	Case 2	(A12a)
		0.4	0,616	>1	Case 2	(A12a)
		0.5	0,616	>1	Case 2	(A8)
FR	**0.0**	0.0	0,050	0,025	Case 3	(A21b)
		0.1	0,050	0,028	Case 3	(A21b)
		0.2	0,050	0,031	Case 3	(A21b)
		0.3	0,050	0,035	Case 3	(A21b)
		0.4	0,050	0,041	Case 3	(A21b)
		0.5	0,050	0,048	Case 3	(A15)
DE	**21.0**	0.0	0,021	0,027	Case 1	(A4)
		0.1	0,021	0,034	Case 1	(A4)
		0.2	0,021	0,045	Case 1	(A4)
		0.3	0,021	0,068	Case 1	(A4)
		0.4	0,021	0,136	Case 1	(A4)
		0.5	0,021	0,300	Case 2	(A8)
HU	**6.0**	0.0	0,338	0,289	Case 2	(A12a)
		0.1	0,338	0,322	Case 2	(A12a)
		0.2	0,338	0,364	Case 2	(A12a)
		0.3	0,338	0,422	Case 2	(A12a)
		0.4	0,338	0,509	Case 2	(A12a)
		0.5	0,338	0,662	Case 2	(A8)
LV	**8.0**	0.0	0,609	0,794	Case 2	(A12a)
		0.1	0,609	0,885	Case 2	(A12a)
		0.2	0,609	>1	Case 2	(A12a)
		0.3	0,609	>1	Case 2	(A12a)
		0.4	0,609	>1	Case 2	(A12a)
		0.5	0,609	>1	Case 2	(A8)

Table A1: continued.

LT	**8.0**	0.0	0,583	0,722	Case 2	(A12a)
		0.1	0,583	0,804	Case 2	(A12a)
		0.2	0,583	0,914	Case 2	(A12a)
		0.3	0,583	>1	Case 2	(A12a)
		0.4	0,583	>1	Case 2	(A12a)
		0.5	0,583	>1	Case 2	(A8)
PL	**6.0**	0.0	0,302	0,252	Case 2	(A12a)
		0.1	0,302	0,280	Case 2	(A12a)
		0.2	0,302	0,316	Case 2	(A12a)
		0.3	0,302	0,366	Case 2	(A12a)
		0.4	0,302	0,440	Case 2	(A12a)
		0.5	0,302	0,566	Case 2	(A8)
RO	**8.0**	0.0	0,466	0,484	Case 2	(A12a)
		0.1	0,466	0,539	Case 2	(A12a)
		0.2	0,466	0,612	Case 2	(A12a)
		0.3	0,466	0,714	Case 2	(A12a)
		0.4	0,466	0,875	Case 2	(A12a)
		0.5	0,466	>1	Case 2	(A8)
SK	**8.0**	0.0	0,322	0,293	Case 2	(A12a)
		0.1	0,322	0,326	Case 2	(A12a)
		0.2	0,322	0,369	Case 2	(A12a)
		0.3	0,322	0,427	Case 2	(A12a)
		0.4	0,322	0,515	Case 2	(A12a)
		0.5	0,322	0,671	Case 2	(A8)
SE	**-4.0**	0.0	0,151	0.057	Case 3	(A21b)
		0.1	0,151	0.062	Case 3	(A21b)
		0.2	0,151	0.069	Case 3	(A21b)
		0.3	0,151	0.077	Case 3	(A21b)
		0.4	0,151	0.087	Case 3	(A21b)
		0.5	0,151	0.100	Case 3	(A15)
UK	**12.5**	0.0	0,080	0,100	Case 1	(A4)
		0.1	0,080	0,108	Case 1	(A4)
		0.2	0,080	0,152	Case 2	(A12a)
		0.3	0,080	0,175	Case 2	(A12a)
		0.4	0,080	0,207	Case 2	(A12a)
		0.5	0,080	0,257	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 section.

[4] For example, Ireland is allowed a 13% increase from 1990 levels by 2008–2012, so its theoretical linear target for 2006 is a rise of no more than 10.4%. Its actual emissions in 2006 show an increase of 25.5% since 1990; hence, its DTPI is 25.5 - 10.4, or 15.1 percentage points. Germany's Kyoto target is a 21% reduction, while its theoretical linear target for 2006 is a decrease of 16.8%. Its actual emissions in 2006 were 18.5% lower than in 1990; hence, Germany's DTPI is (-18.5) - (-16.8), or -1.7 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.* (2010: SOM: Appendix D), the critical emission limitation or reduction δ_{crit} is not adjusted.