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Intra-Union Flexibility of Non-ETS Emission Reduction Obligations in the European Union

Richard S.J. Tol[a,b,c,d]

Abstract: The current EU proposal on greenhouse gas emission reduction has 28 targets for 2020: an EU-wide one for carbon dioxide emissions covered by the European Trading System, and one target for non-ETS emission per Member State. Implementation is necessarily more expensive than needed. I consider three alternative proposals to reduce costs. In the Irish proposal, Member States can purchase ETS permits to offset excess non-ETS emissions. In the Polish proposal, Member States can sell excess non-ETS emissions in the ETS. In the Swedish proposal, Member States can trade their non-ETS allocations. I compare these three alternatives to the default policy (no flexibility outside the ETS) and to the cost-effective solution (full flexibility). I calibrate a simple model to the results of the impact assessment of the European Commission. This reveals that European Commission did not fully disclose all details, and that odd assumptions were made. In the case of three Member States, the non-ETS allocation exceeds the projected emissions. The results show that the alternative flexibility mechanisms would be used to only a limited extent, but would help to suppress the costs of meeting the target. The Swedish and Polish proposals come closest to the cost-effective solution as full use is made of the hot air in the non-ETS system. The Irish proposal performs best if there are negative surprises in either the cost of non-ETS emission reduction or non-ETS emission projections.

Key words: Climate change; Emissions trade; European Union

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[a] Economic and Social Research Institute, Dublin, Ireland
[b] Institute for Environmental Studies, Vrije Universiteit, Amsterdam, The Netherlands
[c] Department of Spatial Economics, Vrije Universiteit, Amsterdam, The Netherlands
[d] Department of Engineering and Public Policy, Carnegie Mellon University, Pittsburgh, PA, USA

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1. Introduction

The European Union has proposed greenhouse gas emission reduction targets for the year 2020 (CEC 2008b). There are a total of 28 targets: one Europe-wide target for emissions covered by the European Trading System (ETS) for carbon dioxide emission permits, and 27 targets (one per Member State) for the remaining greenhouse gases.[1] The initially proposed targets were chosen such that the aggregate emission reduction target would be met in a cost-effective manner.[2] That is, abatement costs are equal at the margin, between ETS and non-ETS and between Member States. However, this equalization is done *ex ante*. Without a trading mechanism, it may be that *ex post* marginal costs differ from one another, if the model or the scenario deviate from reality. Moreover, targets were later adjusted for political reasons. It would therefore be advisable to introduce some form of fungibility between ETS and non-ETS targets even if, given the approximately cost-effective initial allocation of targets, one would not expect that such fungibility would be much used.

Three Member States tabled proposals for flexibility in meeting the non-ETS targets. The Irish government is particularly concerned about the costs of meeting its non-ETS target. It therefore proposed that a government of any Member State would be allowed to purchase ETS permits to offset its excess non-ETS emissions – that is, there is one-directional fungibility from ETS to non-ETS. The Polish government has the opposite concern. It argues that the costs outside the ETS are likely to be lower than inside, and it proposed that Member States be allowed to sell non-ETS emission allowances in the ETS. The Swedish government proposed that ETS and non-ETS be kept separate, but that non-ETS emission allocations be tradable between Member

[1] There are also energy targets, but these are disregarded in this note.

[2] Note that the European Union only mentions the words "fair and equitable" (CEC 2008b). I assume that they first minimized the total costs and then allocated the effort equitably. This follows the principle that one first maximizes the size of the pie before distributing its pieces (Coase 1960). If this principle is not followed, it is possible to reduce everyone's abatement costs and it cannot possibly be fair to impose unnecessary costs (Roemer 1996).

States. Together, these three proposals constitute a single market for all emissions in the European Union. Separately, the three alternative proposals move towards a single market, but do not reach it. Still, each of the three proposals cannot lower welfare, and probably increase. In this paper, I evaluate the three proposals, and their impact on (the distribution of) emission reduction costs.

Although besides the topic of the paper, the calibration of the simple model used here to the results of the impact assessment of the European Commission reveals a number of results that are interesting in their own right – and which cast further doubt either on the technical competence of the European Commission or on the wisdom of making important decisions in haste and without scrutiny (Tol 2007).

Much has been written about the potential of trade in emission permits to reduce the costs of abatement (Manne & Richels 1996;Montgomery 1972;Pizer 2002;Weyant, de la Chesnaye, & Blanford 2006), including in the European Union (Boehringer, Hoffmann, & Manrique-de-Lara-Penate 2006;Klepper & Peterson 2006). I do therefore not set out the general case for (or against) emission permit trade. Nor do I review the past performance of the EU ETS (Convery & Redmond 2007;Ellerman & Buchner 2007;Kruger, Oates, & Pizer 2007). I also do not discuss other inefficiencies in EU climate policy, particularly the overlapping regulation in emissions and energy (Boehringer, Koschel, & Moslener 2008). This paper is focused on the current proposals to enhance the flexibility of meeting the EU's non-ETS emission targets.
Section 2 sets out a simple model, based on (Rehdanz, Tol, & Wetzel 2006;Tol & Rehdanz 2008). Section 3 discusses the calibration of the model and its application. Section 4 concludes.

2. The model

2.1. Model structure and properties

Let us consider a market for tradable emission reduction permits with *I* countries. Emission reduction costs *C* are quadratic. Each country solves the problem:

(1a) $\min_{R_i, P_i} C_i = \alpha_i R_i^2 Y_i + \pi P_i$ s.t. $R_i E_i + P_i \geq E_i - A_i$

R is proportional emission reduction; Y is gross domestic product; P denotes the amount of emission permits bought or sold; π is the emission permit price; assuming a perfect market, all companies face the same price; E are the emissions; A are the allocated emission permits; that is, if a country emits more than has been allocated, $E>A$, it will have to reduce emissions or buy permits on the market; α is a parameter; countries are indexed by i. If a country's allocation exceeds its emissions, $E<A$, the optimization problem is:

(1b) $$\min_{R_j,P_j} C_j = \alpha_j R_j^2 Y_j - \pi R_j E_j + \pi P_j \text{ s.t. } P_j \geq E_j - A_j$$ [3]

We assume that the country sells its hot air $P=E-A$, and in addition reduces emissions by RE which it sells at the market for πRE. Fixing A, we in fact assume that countries with hot air do not have market power. Countries with hot air are indexed by j. Countries without emission reduction targets are excluded from the market.

The first order conditions of (1) are:

(2a) $$\begin{aligned} &2\alpha_i R_i Y_i - \lambda_i E_i = 0, i = 1,2,...,I \\ &2\alpha_j R_j Y_j - \pi E_i = 0, j = 1,2,...,J \end{aligned}$$

(2b) $$\pi - \lambda_i = 0, i = 1,2,...,I$$

(2c) $$\begin{aligned} &R_i E_i + P_i - E_i + A_i = 0, i = 1,2,...,I \\ &P_j - E_j + A_j = 0, j = 1,2,...,J \end{aligned}$$

where λ denotes the Lagrange multiplier. This is a system with $3(I+J)$ equations and $3(I+J)+1$ unknowns, but we also have that aggregate supply must equal aggregate demand, that is

(2d) $$\sum_{i=1}^{I} P_i + \sum_{j=1}^{J} P_j - \sum_{j=1}^{J} R_j E_j = 0$$

which allows us to solve for the permit price π as well. (2) solves as:

(3a) $$\pi = \lambda_i = \frac{\sum_{i=1}^{I}(E_i - A_i) + \sum_{j=1}^{J}(E_j - A_j)}{\sum_{i=1}^{I} \frac{E_i^2}{2\alpha_i Y_i} + \sum_{j=1}^{J} \frac{E_j^2}{2\alpha_j Y_j}}$$

[3] Note that $C_j = \alpha_j R_j^2 Y_j - \pi R_j E_j + \pi P_j = \alpha_j R_j^2 Y_j + \pi\left(P_j - R_j E_j\right) = \alpha_j R_j^2 Y_j + \pi P_j'$ for $P_j' := P_j - R_j E_j$ so that (1b) can be written as $\min_{R_j,P_j} C_j = \alpha_j R_j^2 Y_j + \pi P_j'$ s.t. $R_j E_j + P_j' \geq E_j - A_j$ which is the same as (1a) except that the first E_j-A_j permits are available without emission reduction costs.

(3b) $R_i = \frac{\pi E_i}{2\alpha_i Y_i}; R_j = \frac{\pi E_j}{2\alpha_j Y_j}$

(3c) $P_i = E_i - A_i - \frac{\pi E_i}{2\alpha_i Y_i} E_i; P_j = E_j - A_j$

So, the permit price goes up if the emission reduction obligation increases or if the costs of emission reduction increase. All companies face the same marginal costs of emission reduction, and the trade-off between reducing emissions in-house and buying or selling permits is driven by the ratio of marginal emission reduction costs and the permit price. The modelled market behaves as expected. Note that the solution without the market in emission permits (P_i=0) is trivial.

If country I+1 joins the market, the price becomes

(4) $$\pi^* = \frac{\sum_{i=1}^{I}(E_i - A_i) + \sum_{j=1}^{J}(E_j - A_j) + E_{I+1} - A_{I+1}}{\sum_{i=1}^{I} \frac{E_i^2}{2\alpha_i Y_i} + \sum_{j=1}^{J} \frac{E_j^2}{2\alpha_j Y_j} + \frac{E_{I+1}^2}{2\alpha_{I+1} Y_{I+1}}}$$

A priori, one cannot say whether π^* is larger or smaller than π. The new price π^* would tend be larger than π if country I+1 has a large emission reduction obligation (E-A), and π^* would tend be smaller than π if country I+1 has low emission reduction costs (α). Note that, if I is large, the difference between π^* and π would tend to be small.

Under the Irish proposal outlined in the introduction, the "country" joining the permit market is in fact the non-ETS part of a Member State. Non-ETS emissions would only enter the market if the marginal abatement costs exceed the permit price. Therefore, $\pi^*>\pi$. In the Polish proposal, Member States would purchase ETS permits if these are cheaper than the carbon tax required to meet the non-ETS target. Therefore, $\pi^*<\pi$. Under the Swedish proposal, there would be two markets, and there would be two prices $\pi^{ETS} \neq \pi^{non\text{-}ETS}$.

The questions are, how much would the Irish and Polish proposals affect the ETS price? And how much would the ETS and non-ETS price differ in the Polish proposal? As noted in the introduction, the initial allocation of targets is *ex ante* approximately cost-effective if the PRIMES model and scenario are correct. One would therefore expect prices to deviate by a small amount only. A large deviation would indicate that there major flaws in the models and scenarios used by the European Commission, which is hard to imagine as the European Commission is advised by the best energy and environmental economists in Europe.[4]

2.2. Model calibration

The model is calibrated in four steps. The 2020 emission reduction targets are relative to 2005 emissions. We use two sets of data for total greenhouse gas emissions in 2005: the official country statistics as reported to the UNFCCC, and the emissions reported in impact assessment of the European Commission (Capros et al. 2008). See Table A1. There are substantial, unexplained differences between the data. The UNFCCC data allow for a reasonable approximation of the ETS share in the 2005 emissions.[5] See Table A2. The sector detail is much less for the CEC data, and therefore I use an upper and lower bound of the ETS share, by putting all industry emissions and all non-energy CO2 emissions inside or outside the ETS. I refer to these calibrations as EUmax and EUmin. The CEC study reports total emissions in 2005 and 2020 as well as growth rates for ETS and non-ETS emissions. Together, this implies ETS and non-ETS emissions in 2005 and 2020.[6] This results in negative emissions for Denmark and Luxembourg, so I replaced the ETS share for these countries with average of the upper and lower bound. I refer to this calibration as EUmid.[7] Note that EUmid does not necessarily lies in between EUmax and EUmin (see Table A2), which suggests that there are further problems with the data of Capros *et al*. (2008).

For 2020, I use four alternative projections, viz. (1) the UNFCCC data for 2005 with the ETS and non-ETS growth rates of (Capros, Mantzos, Papandreou, & Tasios

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[4] See http://ideas.repec.org/top/top.ene.html#authors and http://ideas.repec.org/top/top.env.html#authors.

[5] Note that the ETS / non-ETS split is an approximation because the UNFCCC statistics follow the sectoral classification of the International Energy Agency, while the ETS is based on installations. For instance, the power plant of a large university would be classified as "institutional" in the UNFCCC – and would thus be placed outside the ETS even though it is in reality covered.

[6] We know that $E_{2005} + N_{2005} = M_{2005}$, where E_{2005} are ETS emissions in 2005, N are non-ETS emissions and M are total emissions. We also know that $E_{2020} + N_{2020} = E_{2005}(1+g_E)^{15} + N_{2005}(1+g_M)^{15} = M_{2020}$ where g_E is the annual growth rate of ETS emissions, and g_M of non-ETS emissions. Capros *et al.* (2008) report M_{2005}, M_{2020}, g_E and g_M, so that we have two equations and two unknowns (E_{2005}, N_{2005}).

[7] The UNFCCC values for Cyprus and Malta are set equal to their EUmid values.

2008); (2) the EU data for 2005 and 2020 with lower bound ETS; (3) the EU data with upper bound ETS; and (4) the EU data as calibrated above. See Table A1 for the total emissions, and Table A2 for the ETS share.

For each of the four baselines, I calibrate the unit cost parameters α_i for emission reduction in the ETS by assuming that these are proportional to the square root of the relative carbon efficiency of the economy (Rehdanz, Tol, & Wetzel 2006), as follows:

(5) $$\alpha_i \propto 1.57 - 0.17\sqrt{\frac{E_i}{Y_i} - \min_i \frac{E_i}{Y_i}}$$

Furthermore, I assume that π=€40/tCO_2 in 2020 (Capros, Mantzos, Papandreou, & Tasios 2008). See Table A3.

The unit cost parameters α_i for non-ETS emissions are set such that the cost-effective non-ETS emission reduction targets of (Capros, Mantzos, Papandreou, & Tasios 2008) are cost-effective in this model as well. See Table A4. For EUmid, there is a variant: I calibrate the unit cost parameters such that the marginal cost is as reported in the impact assessment of the European Commission (CEC 2008a).[8] I refer to this scenario as EUprice.

3. Results

3.1. Results for the base case

Table 1 shows the marginal emission costs (or the carbon tax, or the domestic price for tradable permits) for the 27 Member States in 2020 for the four alternative calibrations of the split between ETS and non-ETS emissions, and the price variant on EUmid. Note that the EUmid and UNFCCC calibrations yield identical result because the unit cost calibration procedure exactly offsets the differences in 2005 year data. The marginal costs differ substantially from the assumed ETS price of €40/tCO_2. That is, the political adjustments of the cost-effective targets were substantial.

[8] Note that there are four countries with hot air. I keep the unit cost parameters as in the EUmid scenario. For Portugal, I reduced the baseline non-ETS emissions to the target.

Table 1 also reveals that the non-ETS allocation of Bulgaria and Czech Republic is larger than their projected emissions in all five calibrations. For Poland, this holds for four calibrations, while Portugal has hot air in one calibration. These entries are marked as "hot air" in Table 1.[9]

Table 1 identifies the nine countries that would purchase ETS permits to offset non-ETS emissions in the Irish proposal. Eighteen countries would sell non-ETS emissions to the ETS in the Polish proposal. The trade pattern is stable across the baseline calibrations, but in the EUprice variant on EUmid, a few countries change position.

Table 2 shows the carbon prices in the ETS according to the five calibration and the five policy cases. Without fungibility between ETS and non-ETS emissions, the ETS price would be €40/tCO_2, and the carbon price outside the ETS would be as in Table 1. With the Irish proposal, the ETS price would increase by up to €4/tCO_2. This price would apply to ETS emissions in all Member States and to non-ETS emissions in those Member States marked with a single asterisk* in Table 1. The price increases because selected Member States purchase ETS permits to offset excess non-ETS emissions by the amount given in Table 3. With the Polish proposal, the ETS price would fall by €7 to €11/tCO_2eq. This price would apply to ETS emissions in all Member States and to non-ETS emissions in those Member States marked with a double asterisk** in Table 1. The price goes down because selected Member States sell excess non-ETS emissions by the amount given in Table 3. With the Swedish proposal, the ETS price would be unchanged. The non-ETS price would be between €27 and €31/tCO_2eq for all Member States. With full emissions trading (the Irish plus Polish plus Swedish proposal), the permit price would be between €34 and €36/tCO_2eq. This price would apply to all emissions in all Member States. Table 3 shows that there is indeed a net sale of emission permits into the ETS.

Table 3 also shows that in all cases and under all proposals, the flow of permits to or from the ETS is modest. Under the Irish proposal, less than 3% of ETS permits would

[9] The calibration procedure described above implies $\alpha<0$ for these countries; α was reset to the EU average.

be used to offset non-ETS emissions. Under the Polish proposal, ETS emissions would grow by less than 7%.

Under the Swedish proposal, ETS emissions are unchanged. This does imply, however, that the non-ETS market has 27 buyers and sellers only. This may imply market power. Table A5 shows the trading pattern. With 14 sellers and 13 buyers, an equal market share would be 7 to 8%. Two sellers stand out (Poland, Romania) and two buyers (Italy, Spain). These countries may be able to exert a degree of monopoly or monopsony power. That is, Poland and Romania may withhold some of their emissions from the market in order to drive up the price, while Italy and Spain may suppress their demand in order to reduce the price. The results presented in this paper do not consider this. The ability to exert market power depends on the structure of the market, no proposals for which have yet been made. However, a continuous double auction may be the most appropriate choice in situations like this (Carlen 2003).

Table 4 shows the total costs of emission reduction, here presented as a percent of GDP in 2020. Each of the four proposals improves welfare in each calibration, as they should. In each calibration, the Irish proposal has the smallest effect, followed by the Polish proposal, the Swedish proposal, and (as expected) full trade. Table 5 shows the total costs for the five alternative policies per Member State for the EUmid calibration. Costs vary widely, with Latvia the biggest loser and Bulgaria the biggest winner as it expects to export a lot of permits. Table 5 also shows which Member State would support / oppose which policy the most. The Member States are unanimous that the unreformed ETS is suboptimal, but different Member States prefer different alternatives.[10]

3.2. Sensitivity analysis

Showing results for five alternative calibrations, some of the sensitivities of the results to the assumptions are explored above. However, the five alternative calibrations have different baseline emissions as well as different reduction costs, and these two differences are calibrated to offset one another. This explains why the EUprice

[10] Interestingly, the Irish, Poles and Swedes do not prefer the proposals named after them.

calibration stands out. I therefore show five additional sets of results, based on the EUmid calibration.

First, I increase the non-ETS emissions for 2020 for Ireland based on a recent projection for that country (Fitz Gerald et al. 2008). Second, I increase the non-ETS emissions for 2020 for all Member States, applying the same ratio for the growth rate as for Ireland. Specifically, the growth in non-ETS emissions between 2005 and 2020 is multiplied by a factor 1.14. Third, I increase the unit cost of non-ETS emission reduction in Ireland so as to match a recent projection for that country (Cambridge Econometrics 2008). Fourth, I increase the unit cost of non-ETS emission reduction in all Member States by the same factor (3.1). Fifth, I increase emissions as in the second scenario and reduction costs as in the fourth scenario.

Table 6 shows the effect of the price of emission permits in 2020, Table 7 the impact on total costs, and Table 8 the net demand on ETS emissions. As I either increased the emission reduction obligation, or the costs of abatement, or both, it is no surprise that both the marginal and total cost of emission reduction go up. As the perturbations of emissions and costs are in the non-ETS sectors, the ETS is not affected if there is no fungibility between ETS and non-ETS. As emission reduction outside the ETS becomes more expensive, the Polish proposal loses much of its appeal – most of the hot air in the EUmid scenario disappears, with only a small amount left in Bulgaria. Table 7 shows that the costs escalate in the Polish proposal almost as much as in case of the current ETS. Costs also escalate in the Swedish proposal, but less.

The Irish proposal, on the other hand, behaves much like full trade. Indeed, in the full trade case, there would be less reason to sell non-ETS emission to the ETS (as in the Polish proposal) and less reason to trade non-ETS emissions between Member States (as in the Swedish proposal). Instead, the market would seek to buy more ETS emission permits to offset non-ETS emissions (as in the Irish proposal). Table 8 highlights this.

Figure 1 shows the impact on the total costs of emission reduction if unit emission reduction costs are either higher of lower than in the base case.[11] The case with higher unit emission reduction costs is described above. The case with lower unit emission reduction costs uses the inverse ratio – that is, the unit costs of the base case are multiplied with the ratio of base case costs to high case costs. In Figure 1, the costs for each of the five policy scenarios are normalized to unity for the unit costs calibrated to PRIMES. If unit costs are higher, total costs go up in all policy scenarios. Costs increase most under the Polish proposal, and least under the Irish proposal – as discussed above. If unit costs are lower, total costs go down in all policy scenarios. Costs decrease most under the Polish proposal, and almost as much under full trade. The current ETS is in the middle, and very close to costs under the Irish proposal. The costs decrease least under the Swedish proposal. The Polish proposal best exploits positive surprises in the non-ETS sectors, while the Irish proposal is most robust against negative surprises. However, scale is important too – the absolute loss of a negative surprise is 1.03% (0.36%) of GDP under the Polish (Irish) proposal, but the absolute gain of the positive surprise is 0.54% (0.28%) of GDP under the Polish (Irish) proposal. If both types of surprises were equally likely, a risk averse decision maker would prefer the Irish proposal.

4. Discussion and conclusion

In this paper, I discuss the implications of intra-EU flexibility in meeting the non-ETS emission reduction targets, using a simple model calibrated to the impact assessment of the European Commission DG Environment (Capros, Mantzos, Papandreou, & Tasios 2008). The following results emerge.

Firstly, the non-ETS emission allocation is advertised by the European Commission as approximately cost-effective, but the analysis here shows substantial deviation from a uniform carbon price between ETS and non-ETS, and between non-ETS emissions in different Member States.

[11] The case with lower non-ETS emissions than in EUmid has a substantial amount of hot air, and is not considered further.

Secondly, it appears that at least two countries have received non-ETS allocations that exceed their emissions as projected by CEC DG Environment (Capros, Mantzos, Papandreou, & Tasios 2008).

Thirdly, the Irish proposal to allow Member States to purchase ETS permits to offset excess non-ETS emissions would increase the price of emission permits by less than 10%. The Polish proposal to allow Member States to sell non-ETS emissions into the ETS would decrease the price of emission permits by more than 15%. The Swedish proposal to allow Member States to sell non-ETS emission allocations to one another would have non-ETS emission permits trading at a price that is 25% or more lower than the ETS price. The first-best solution, a single market for all emissions, would settle on a price that is at least 10% below the projected ETS price of €40/tCO_2eq. From a welfare perspective, the single ETS plus non-ETS market performs best. The Polish and Swedish proposals perform roughly the same, and better than the Irish proposal, which in turn outperforms current policy. However, from the perspective of maintaining a strong carbon price signal in the ETS sector, the Irish proposal is the preferred option.

Fourthly, the Irish proposal emerges as the preferred alternative (after, of course, a complete market) if either non-ETS emissions or reduction costs were higher than anticipated. This follows directly from the structure of the proposal. The Polish proposal would fare better if non-ETS emissions or reduction costs were lower, or if ETS emissions and reductions were higher. The choice between the Irish and Polish proposal in the face of such uncertainty is therefore a judgement call. However, ETS emissions are characterized by large point sources and slow capital turnover. Non-ETS emissions are more diffuse and more dynamic. One can therefore argue that non-ETS emissions and reduction costs are more uncertain. Such uncertainty is underlined by the fact that the impact assessment of the European Commission does not reproduce the historical record. The Irish proposal is more robust to such uncertainty, while the Polish proposal is not.

The results presented here come with all the usual caveats. The numbers depend on a range of assumptions, each of which is uncertain and disputable. It would therefore be recommendable to reproduce the analysis here with other models. More complicated models may find that the model used here is oversimplified. However, the qualitative results are probably robust as they follow intuitively from the structure of the problem and the alternative policies. There are also things that were not considered in this paper. Chief among these are potential market power under the Swedish proposal, and the ability to purchase emission permits outside the European Union (through the Clean Development Mechanism or its successor), including the proposed limitations imposed on that as well as the option to trade CDM allocations. These issues are deferred to future research.

In sum, the European Union has created a potential economic problem by imposing 28 emission reduction targets of varying strictness. If for political reasons it is not feasible to replace the 28 targets with a single one, then the Irish proposal to allow Member States to purchase ETS emission permits to offset excess non-ETS emissions emerges as a policy that would maintain, or even strengthen the integrity of the ETS while at the same time controlling the costs on non-ETS emission reduction.

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Table 1. Marginal emission reduction costs (in €/tCO_2eq) in 2020 in the 25 Member States according to three alternative calibrations of the ETS/non-ETS split of emissions.

	EUmin	EUmid	EUmax	EUprice	UNFCCC
ETS	40.00	40.00	40.00	40.00	40.00
Non-ETS					
Austria*	42.51	42.67	42.49	62.00	42.67
Belgium**	35.73	35.96	36.32	42.00	35.96
Bulgaria**	Hot air	Hot air	Hot air	Hot air	Hot air
Cyprus**	26.31	23.62	25.60	31.00	23.62
Czechia**	Hot air	Hot air	Hot air	Hot air	Hot air
Denmark*	68.99	77.78	67.56	81.00	77.78
Estonia**	14.29	4.17	3.32	4.00	4.17
Finland**	38.42	38.38	38.87	20.00	38.38
France**	37.59	37.40	37.59	37.00	37.40
Germany*	40.37	40.43	40.31	25.00**	40.43
Greece**	19.43	19.47	20.50	27.00	19.47
Hungary**	5.29	4.52	5.34	5.00	4.52
Ireland*	49.84	54.66	53.14	57.00	54.66
Italy*	44.57	45.05	44.57	92.00	45.05
Latvia**	22.61	20.24	19.64	71.00	20.24
Lithuania**	5.55	4.43	2.82	3.00	4.43
Luxembourg*	47.55	47.80	47.21	88.00	47.80
Malta**	19.33	12.39	19.33	22.00	12.39
The Netherlands*	45.72	47.02	46.05	47.00	47.02
Poland**	5.55	Hot air	Hot air	Hot air	Hot air
Portugal**	11.68	3.59	7.11	Hot air	3.59
Romania**	7.56	3.75	1.72	4.00	3.75
Slovakia**	9.15	2.28	0.59	2.00	2.28
Slovenia**	20.68	21.08	21.43	63.00*	21.08
Spain**	35.47	34.79	35.28	72.00*	34.79
Sweden*	43.96	46.04	46.70	87.00	46.04
UK*	54.88	80.00	58.16	19.00**	80.00

* Purchases ETS permits in the Irish proposal.

** Sells ETS permits in the Polish proposal.

Table 2. The price of carbon (in €/CO_2eq) inside and outside the ETS for five alternative policies and five alternative calibrations.

Panel A. ETS

	EUmin	EUmid	EUmax	EUprice	UNFCCC
ETS	40.00	40.00	40.00	40.00	40.00
Irish	42.33	41.21	41.42	44.41	41.70
Polish	29.15	30.53	33.21	29.69	30.63
Swedish	40.00	40.00	40.00	40.00	40.00
Full trade	34.22	34.83	36.05	36.42	35.60

Panel B. Non-ETS

	EUmin	EUmid	EUmax	EUprice	UNFCCC
ETS	Table 1	Table 1	Table 1	Table 1	Table 1
Irish	Table 1**	Table 1**	Table 1**	Table 1**	Table 1**
Polish	Table 1*	Table 1*	Table 1*	Table 1*	Table 1*
Swedish	30.82	27.40	30.68	30.67	30.16
Full trade	34.22	34.83	36.05	36.42	35.60

Table 3. The net change in total available emission permits (in million metric tones of carbon dioxide) in the ETS for five alternative policies and five alternative calibrations; for comparison, the initial amount of ETS permits is given too, as well as the net change in percent of the initial amount.

	EUmin	EUmid	EUmax	Euprice	UNFCCC
ETS	0	0	0	0	0
Irish	-24	-21	-24	-75	-20
Polish	110	162	137	177	112
Swedish	0	0	0	0	0
Full trade	59	89	66	61	53
Total permits	1,654	2,733	2,649	2,733	1,907
Irish (%)	-1.43	-0.76	-0.90	-2.76	-1.07
Polish (%)	6.67	5.93	5.17	6.46	5.87
Full trade (%)	3.56	3.24	2.49	2.24	2.76

Table 4. The total cost of emission reduction (in %GDP) for five alternative policies and five alternative calibrations.

	EUmin	EUmid	EUmax	Euprice	UNFCCC
ETS	1.215	1.313	1.364	1.484	1.022
Irish	1.204	1.298	1.353	1.386	1.004
Polish	1.072	1.146	1.221	1.313	0.903
Swedish	1.044	1.159	1.218	1.192	0.891
Full trade	1.026	1.123	1.198	1.174	0.874

Table 5. The total cost of emission reduction (in %GDP) in each Member States for five alternative policies for the EUmid calibration; the right most columns denote the most and least preferred policy.

	ETS	Irish	Polish	Swedish	Full trade	Best	Worst
Austria	-1.82	-1.84	-1.62	-1.74	-1.70	P	I
Belgium	-1.98	-2.00	-1.79	-1.95	-1.90	P	I
Bulgaria	10.11	11.05	7.79	13.44	10.90	S	P
Cyprus	-0.36	-0.36	-0.37	-0.35	-0.31	F	P
Czechia	1.12	1.25	1.53	2.14	2.16	F	E
Denmark	-1.46	-1.26	-1.37	-1.06	-1.12	S	E
Estonia	-0.52	-0.35	-0.67	0.13	-0.01	S	P
Finland	-1.54	-1.56	-1.36	-1.52	-1.46	P	I
France	-0.64	-0.64	-0.60	-0.60	-0.63	P	I
Germany	-0.97	-0.95	-1.02	-0.95	-1.01	P	S
Greece	-1.01	-1.01	-0.88	-0.96	-0.82	F	E
Hungary	-1.77	-1.73	-1.34	-1.35	-1.13	F	E
Ireland	-2.13	-2.11	-1.87	-1.93	-1.88	P	E
Italy	-2.30	-2.32	-2.04	-2.19	-2.13	P	I
Latvia	-5.08	-5.17	-4.11	-4.99	-4.29	P	I
Lithuania	-2.04	-2.08	-0.77	-1.34	-0.62	F	I
Luxembourg	-1.99	-1.97	-1.90	-1.70	-1.83	S	E
Malta	3.10	3.21	2.49	3.24	2.96	S	P
The Netherlands	-2.38	-2.40	-2.07	-2.27	-2.18	P	I
Poland	-1.61	-1.59	0.06	-0.26	0.52	F	E
Portugal	-2.08	-2.11	-1.55	-1.87	-1.59	P	I
Romania	-2.34	-2.22	-1.35	-1.14	-0.66	F	E
Slovakia	-2.25	-2.19	-1.65	-1.60	-1.34	F	E
Slovenia	-1.86	-1.87	-1.60	-1.81	-1.55	F	I
Spain	-1.42	-1.43	-1.30	-1.38	-1.36	P	I
Sweden	-1.82	-1.85	-1.56	-1.72	-1.64	P	I
UK	-1.01	-0.96	-0.96	-0.92	-0.92	S	E

Table 6. The price of carbon (in €/CO_2eq) in the ETS for the EUmid calibration and five variations that have higher non-ETS emissions in Ireland and the entire EU, higher costs in Ireland and the entire EU, or both higher non-ETS emissions and higher costs (entire EU only).

	EUmid	Higher emissions		Higher costs		Both
		Ireland	EU27	Ireland	EU27	EU27
ETS	40.00	40.00	40.00	40.00	40.00	40.00
Irish	41.21	41.51	49.71	41.42	51.06	68.42
Polish	30.53	30.53	35.75	30.53	35.59	39.73
Swedish	27.40	27.98	56.04	27.63	83.86	171.53
Full trade	34.83	35.05	47.29	34.95	48.13	68.16

Table 7. The total cost of emission reduction (in %GDP) for the EUmid calibration and five variations that have higher non-ETS emissions in Ireland and the entire EU, higher costs in Ireland and the entire EU, or both higher non-ETS emissions and higher costs (entire EU only).

	EUmid	Higher emissions		Higher costs		Both
		Ireland	EU27	Ireland	EU27	EU27
ETS	1.313	1.342	2.694	1.343	2.219	6.446
Irish	1.298	1.317	2.352	1.303	1.653	3.380
Polish	1.146	1.192	2.651	1.193	2.173	6.445
Swedish	1.159	1.188	2.354	1.176	1.793	5.405
Full trade	1.123	1.159	2.289	1.146	1.579	3.377

Table 8. The net change in total available emission permits (in million metric tones of carbon dioxide) in the ETS for the EUmid calibration and five variations that have higher non-ETS emissions in Ireland and the entire EU, higher costs in Ireland and the entire EU, or both higher non-ETS emissions and higher costs (entire EU only).

	EUmid	Higher emissions		Higher costs		Both
		Ireland	EU27	Ireland	EU27	EU27
ETS	0	0	0	0	0	0
Irish	-21	-26	-166	-24	-189	-487
Polish	162	162	73	162	76	5
Swedish	0	0	0	0	0	0
Full trade	89	85	-125	87	-139	-482

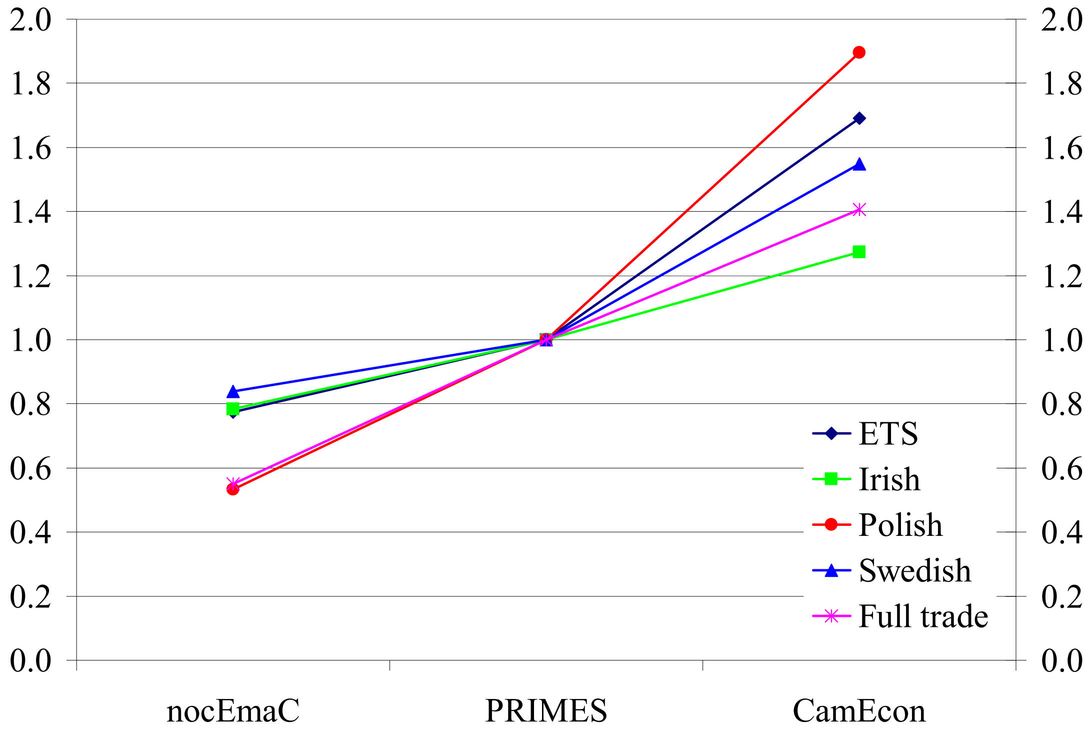

Figure 1. Indexed costs of emission reduction under five different policy proposals and three calibrations of the unit costs parameters; PRIMES corresponds to EUmid above.

Table A1. Greenhouse gas emissions (million metric tonne of carbon dioxide equivalent) in 2005 and 2020, and the average annual growth rate.

	EU			UNFCCC		
	2005	2020	growth	2005	2020	Growth
Austria	97.9	104.2	0.42	79.3	83.6	0.35
Belgium	141.4	152.5	0.51	123.4	131.1	0.41
Bulgaria	65.2	68.4	0.32	54.0	56.1	0.26
Cyprus	8.6	8.5	-0.08	8.6	8.4	-0.16
Czechia	145.4	143.0	-0.11	125.3	123.5	-0.09
Denmark	66.0	64.5	-0.16	50.2	49.0	-0.16
Estonia	18.9	21.7	0.93	16.5	19.0	0.94
Finland	69.1	70.6	0.14	56.6	57.5	0.10
France	561.0	555.7	-0.06	417.2	407.9	-0.15
Germany	1003.3	999.4	-0.03	876.8	858.4	-0.14
Greece	131.8	136.6	0.24	110.3	112.8	0.14
Hungary	78.9	90.8	0.94	61.3	70.2	0.91
Ireland	75.8	80.7	0.42	47.6	50.9	0.44
Italy	575.7	644.6	0.76	490.3	543.4	0.69
Latvia	10.8	17.8	3.39	7.5	12.2	3.28
Lithuania	19.3	23.5	1.32	12.1	14.8	1.37
Luxembourg	13.9	15.1	0.55	14.2	15.4	0.55
Malta	3.5	2.8	-1.48	3.5	3.0	-1.01
Netherlands	220.8	241.5	0.60	175.8	190.9	0.55
Poland	373.6	423.1	0.83	316.8	358.2	0.82
Portugal	87.3	97.3	0.73	68.0	75.1	0.67
Romania	149.4	189.8	1.61	105.4	133.6	1.59
Slovakia	50.5	60.7	1.23	40.7	48.5	1.18
Slovenia	19.7	23.2	1.10	16.8	19.6	1.06
Spain	449.6	491.8	0.60	367.0	395.0	0.49
Sweden	70.0	82.6	1.11	52.3	60.9	1.02
UK	703.8	684.3	-0.19	558.2	527.0	-0.38
EU27	5211.2	5494.6	0.35	4255.6	4426.1	0.26

Table A2. The share of ETS in total emissions (cf. Table A1) in four alternative calibrations.

	EUmin		EUmid*		EUmax		UNFCCC	
	2005	2020	2005	2020	2005	2020	2005	2020
Austria	0.20	0.22	0.49	0.51	0.47	0.48	0.33	0.35
Belgium	0.18	0.22	0.55	0.57	0.41	0.42	0.34	0.36
Bulgaria	0.43	0.43	0.67	0.70	0.61	0.63	0.60	0.63
Cyprus	0.41	0.34	0.36	0.31	0.47	0.41	0.42	0.37
Czechia	0.44	0.39	0.51	0.47	0.66	0.62	0.49	0.46
Denmark	0.34	0.33	0.40	0.40	0.46	0.45	0.46	0.46
Estonia	0.60	0.57	0.58	0.58	0.68	0.69	0.80	0.80
Finland	0.33	0.39	0.56	0.59	0.56	0.58	0.52	0.55
France	0.11	0.09	0.13	0.11	0.29	0.27	0.24	0.22
Germany	0.35	0.37	0.73	0.75	0.53	0.54	0.43	0.44
Greece	0.38	0.36	0.42	0.40	0.51	0.49	0.60	0.58
Hungary	0.24	0.25	0.60	0.61	0.36	0.37	0.39	0.40
Ireland	0.20	0.22	0.39	0.44	0.33	0.37	0.41	0.46
Italy	0.27	0.28	0.51	0.53	0.47	0.48	0.38	0.40
Latvia	0.20	0.20	0.43	0.47	0.31	0.37	0.32	0.35
Lithuania	0.31	0.32	0.33	0.34	0.38	0.40	0.44	0.45
Luxembourg	0.09	0.09	0.17	0.16	0.24	0.24	0.18	0.17
Malta	0.54	0.32	0.52	0.33	0.54	0.32	0.42	0.25
Netherlands	0.30	0.34	0.45	0.50	0.46	0.50	0.42	0.47
Poland	0.46	0.44	0.36	0.36	0.58	0.58	0.60	0.60
Portugal	0.31	0.34	0.50	0.54	0.47	0.50	0.44	0.49
Romania	0.30	0.30	0.51	0.52	0.54	0.57	0.47	0.48
Slovakia	0.31	0.30	0.55	0.57	0.59	0.61	0.46	0.48
Slovenia	0.31	0.28	0.42	0.38	0.48	0.44	0.46	0.42
Spain	0.28	0.25	0.19	0.18	0.50	0.48	0.43	0.42
Sweden	0.11	0.11	0.35	0.41	0.38	0.45	0.30	0.35
UK	0.32	0.33	0.70	0.72	0.46	0.47	0.40	0.43
EU27	0.30	0.30	0.49	0.50	0.48	0.48	0.42	0.43

* The EUprice scenario uses the same projections as EUmid.

Table A3. Unit cost parameters in ETS according to five alternative calibrations; the EU27 is the weighted average, using baseline emissions as weights; the last two columns show the mean and standard deviation.

	EUmin	EUmid	EUmax	EUprice	UNFCCC	mean	st.dev.
Austria	13.8	19.8	19.6	19.8	15.3	17.6	2.9
Belgium	13.8	19.6	19.6	19.6	15.2	17.5	2.9
Bulgaria	13.0	18.4	18.3	18.4	14.3	16.5	2.6
Cyprus	13.6	19.9	19.6	19.9	15.1	17.6	3.0
Czechia	13.3	19.2	18.8	19.2	14.8	17.1	2.8
Denmark	13.8	20.0	19.8	20.0	15.3	17.8	3.0
Estonia	13.0	19.0	18.6	19.0	14.3	16.8	2.9
Finland	13.6	19.7	19.5	19.7	15.1	17.5	2.9
France	14.1	20.6	20.2	20.6	15.7	18.2	3.1
Germany	13.6	19.5	19.5	19.5	15.2	17.5	2.8
Greece	13.5	19.7	19.3	19.7	14.9	17.4	3.0
Hungary	13.6	19.3	19.4	19.3	15.0	17.3	2.8
Ireland	13.8	19.9	19.8	19.9	15.3	17.7	2.9
Italy	13.7	19.7	19.5	19.7	15.2	17.6	2.9
Latvia	13.7	19.5	19.4	19.5	15.1	17.4	2.8
Lithuania	13.5	19.7	19.4	19.7	15.1	17.5	2.9
Luxembourg	14.0	20.2	20.0	20.2	15.5	18.0	3.0
Malta	13.6	19.9	19.7	19.9	15.2	17.7	3.0
Netherlands	13.7	19.7	19.5	19.7	15.2	17.6	2.9
Poland	13.2	19.4	18.8	19.4	14.6	17.1	2.9
Portugal	13.6	19.5	19.3	19.5	15.0	17.4	2.9
Romania	13.3	19.0	18.7	19.0	14.7	16.9	2.7
Slovakia	13.4	19.1	18.8	19.1	14.8	17.1	2.7
Slovenia	13.6	19.6	19.3	19.6	15.0	17.4	2.9
Spain	13.7	20.2	19.5	20.2	15.2	17.8	3.1
Sweden	14.1	20.1	19.9	20.1	15.5	17.9	2.9
UK	13.7	19.7	19.7	19.7	15.3	17.6	2.9
EU27	13.6	19.6	19.4	19.6	15.1	17.5	2.9

Table A4. Unit cost parameters in non-ETS according to five alternative calibrations; the EU27 is the weighted average, using baseline emissions as weights; the last two columns show the mean and standard deviation.

	EUmin	EUmid	EUmax	EUprice	UNFCCC	mean	st.dev.
Austria	26.6	17.6	17.4	25.6	18.6	21.2	4.5
Belgium	30.4	16.0	20.1	18.6	20.5	21.1	5.5
Bulgaria	81.0	65.6	70.8	65.6*	67.0	70.0	6.5
Cyprus	23.4	28.2	21.7	37.0	25.5	27.2	6.0
Czechia	58.0	51.0	33.4	51.0*	45.4	47.8	9.2
Denmark	26.7	29.9	21.0	31.1	20.3	25.8	5.0
Estonia	24.9	30.2	23.2	29.0	12.7	24.0	6.9
Finland	36.2	24.5	18.6	12.8	21.9	22.8	8.7
France	25.4	26.4	20.5	26.1	17.0	23.1	4.2
Germany	38.9	17.7	24.5	10.9	33.2	25.0	11.3
Greece	29.2	27.3	22.4	37.8	15.7	26.5	8.2
Hungary	34.3	18.3	28.8	20.2	21.5	24.6	6.7
Ireland	23.5	23.5	24.0	24.5	14.4	22.0	4.3
Italy	26.9	19.1	19.4	39.0	20.6	25.0	8.4
Latvia	17.3	12.4	14.9	43.4	10.3	19.7	13.5
Lithuania	22.5	22.2	20.9	15.0	11.6	18.5	4.9
Luxembourg	23.7	22.0	19.1	40.6	22.2	25.5	8.6
Malta	21.4	26.8	21.4	47.5	32.1	29.8	10.8
Netherlands	28.7	26.0	22.9	26.0	22.0	25.1	2.7
Poland	37.5	48.7	32.5	48.7*	25.9	38.6	10.0
Portugal	34.6	29.8	29.5	29.8*	25.6	29.8	3.2
Romania	38.7	28.3	26.5	30.2	21.4	29.0	6.3
Slovakia	38.3	27.4	25.8	24.1	26.4	28.4	5.7
Slovenia	24.9	21.0	18.7	62.8	16.6	28.8	19.2
Spain	21.7	26.7	15.7	55.3	15.2	26.9	16.6
Sweden	12.8	11.7	11.9	22.1	9.5	13.6	4.9
UK	38.7	41.3	36.8	9.8	64.9	38.3	19.6
EU27	32.4	28.2	24.8	32.0	29.4	29.4	3.1

* As in EUmid.

Table A5. Net demand (million metric tonne of carbon dioxide equivalent) according to five alternative calibrations under the Swedish proposal. Net sellers (buyers) with a market share above 14% are indicated in *italics* (**bold**).

	Eumin	EUmid	EUmax	EUprice	UNFCCC	mean	share*
Austria	4.4	3.4	2.9	4.8	3.0	3.7	3.5
Belgium	2.8	2.8	2.7	3.2	2.4	2.8	2.6
Bulgaria	-11.8	-6.9	-8.4	-7.1	-7.2	-8.3	-7.9
Cyprus	-0.1	-0.1	-0.1	0.0	-0.2	-0.1	-0.1
Czechia	-13.7	-10.9	-8.1	-11.9	-10.5	-11.0	-10.5
Denmark	4.9	4.5	4.1	4.3	2.9	4.1	3.9
Estonia	-1.2	-1.3	-1.2	-1.6	-0.6	-1.2	-1.1
Finland	0.9	0.8	0.9	-1.6	0.6	0.3	0.3
France	14.0	18.9	11.5	12.1	8.8	13.0	12.4
Germany	16.6	8.2	14.3	-5.7	12.1	9.1	8.6
Greece	-5.3	-3.4	-3.9	-1.1	-2.7	-3.3	-3.1
Hungary	-11.7	-5.4	-9.8	-5.5	-7.2	-7.9	-7.5
Ireland	5.6	4.1	4.2	3.8	2.3	4.0	3.8
Italy	**29.2**	**22.5**	**21.3**	**38.3**	**20.5**	**26.3**	**25.0**
Latvia	-1.5	-0.8	-1.5	1.3	-0.9	-0.7	-0.7
Lithuania	-3.2	-2.8	-3.0	-4.9	-1.6	-3.1	-2.9
Luxembourg	1.4	1.5	1.2	2.2	1.3	1.5	1.4
Malta	-0.1	-0.1	-0.1	0.0	-0.2	-0.1	-0.1
Netherlands	9.3	7.8	6.9	6.5	5.7	7.2	6.9
Poland	*-40.4*	*-45.4*	*-33.5*	*-50.7*	*-26.5*	*-39.3*	*-37.3*
Portugal	-5.4	-3.8	-4.4	-4.8	-3.6	-4.4	-4.2
Romania	*-28.9*	*-18.7*	*-19.9*	*-19.7*	*-15.8*	*-20.6*	*-19.6*
Slovakia	-6.5	-4.0	-4.2	-5.2	-4.3	-4.9	-4.6
Slovenia	-1.3	-0.7	-0.9	1.2	-0.8	-0.5	-0.5
Spain	**10.2**	**16.1**	**6.9**	**43.5**	**5.7**	**16.5**	**15.7**
Sweden	6.6	4.5	3.3	7.2	3.1	4.9	4.7
UK	25.4	9.2	19.1	-8.6	13.7	11.8	11.2

* The share in total demand (if positive) or total supply (if negative), percent.

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