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Costs and fairness of forest carbon sequestration in EU climate policy

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Abstract

Large emissions of greenhouse gases are expected to cause major environmental problems in the future. European policy makers have therefore declared that they aim to implement cost-efficient and fair policies to reduce carbon emissions. The purpose of this paper is to assess whether the cost of the EU policies for 2020 can be reduced through the inclusion of carbon sequestration as and abatement option while also equity is improved. The assessment is done by numerical calculations using a chance-constrained partial equilibrium model of the EU Emissions Trading Scheme and national effort-sharing targets, where forest sequestration is introduced as an uncertain abatement option. Fairness is evaluated by calculation of Gini-coefficients for six equity criteria to policy outcomes. The estimated Gini-coefficients range between 0.11 and 0.32 for the current policy, between 0.16 and 0.66 if sequestration is included and treated as certain, and between 0.19 and 0.38 when uncertainty about sequestration is taken into account and policy-makers wish to meet targets with at least 90 percent probability. The results show that fairness is reduced when sequestration is included and that the impact is larger when sequestration is treated as certain.

Keywords: carbon sequestration, costs, fairness, EU climate policy

JEL: D63, Q48, Q52, Q58,

1. Introduction

Climate change is a long-term threat to the environment and to human life with potentially serious consequences (IPCC, 2007). Policy-makers in Europe have adopted EU-wide policies to reduce the amount of carbon emitted to the atmosphere. Both cost-efficiency and equity were stated to be key decision criteria when implementing the EU climate policy (European Commission, 2008a; 2008b).

Carbon emissions can be reduced through reductions in fossil fuel consumption, but also through increased use of renewable energies, improved energy efficiency, and increased carbon sequestration. Carbon sequestration is here defined as the net uptake of carbon from the atmosphere by vegetation and soils. Currently, carbon sequestration is not an accepted abatement method within EU's climate policy. Arguments against sequestration are, e.g. the uncertainty and non-permanence in delivering emission reductions as well as the lack of harmonized methods for monitoring and reporting changes in sequestration from land use, land-use change and forestry (European Commission, 2008a). The European Commission also fears that the inclusion of sequestration would reduce the simplicity, transparency and predictability of the EU ETS (EU Emissions Trading Scheme).

However, carbon sequestration has a great potential in reducing the overall cost of meeting the targets (Bosetti et al., 2009; Gren et al., 2012; Murray et al., 2009; Sohngen, 2009) and should therefore be an interesting option for politicians who are concerned with cost-efficiency. Nevertheless, the introduction of a cheap abatement option, such as carbon sequestration, could alter the cost allocation among countries. Therefore, the fairness of the policy could either increase or decrease. Countries with large areas of forest land, high sequestration per unit of land, and low uncertainty about sequestration would benefit more from the inclusion of sequestration. The impact on equity will, however, depend on whether these countries carry more or less of the burden under the current policy, compared to the average European country.

The purpose of this paper is to assess whether the cost of the EU policies for 2020 can be reduced through the inclusion of carbon sequestration as an abatement option while also equity is improved. Fairness is assessed based on the outcome of cost-efficient policies which meet EU targets for 2020, with and without forest carbon sequestration. These targets are *(i)* a 21 percent emission reduction in the ETS sectors (Official Journal, 2009a) and *(ii)* national targets for the non-ETS sectors, i.e. the non-trading sectors, corresponding in total to a 10 percent reduction (Official Journal, 2009b) compared to the 2005 level. The member state target is divided among member states taking, among other criteria, GDP per capita differences into account (European Commission, 2008b).

The costs of carbon reductions are relatively straightforward to calculate, but the assessment of fairness is more challenging since there is no single definition and operationalization of the concept. We therefore use different theories of justice, with associated equity principles, for the definition of operative equity criteria. These equity criteria are then evaluated through the calculation of Gini-coefficients.

Many previous studies have discussed ethical issues with a main focus on the damage cost of climate change (e.g. Dietz et al. 2008; Srinivasan, 2010). Our focus is, however, rather on the equity of climate policy. This issue is analyzed in the literature through examination of the impact on costs of applying different fair rules for the allocation of emission reductions across countries or different fair initial allocations of tradable emission permit (Blanchard et al., 2003; Bosello and Roson, 2002; Bosello et al., 2003; Groot, 2010; Kverndokk and Rose, 2008; Mattoo and Subramanian, 2011; Metz, 2000; Ringius et al., 1998). Several equity principles are then operationalized and applied to international climate policy (Ringius et al., 1998; Rose et al., 1998; Schmidt and Koschel, 1998). Rose et al. (1998) examine nine equity principles which lay the basis for the distribution of emission permits, and the associated welfare effects on nine world regions. Their simulations show that the net cost or net benefit after emission trading is similar for several principles e.g. *sovereignty* and *horizontal*, but the outcome under the *egalitarian* principle differs, as all the industrialized countries are buyers and all the developing countries are sellers of permits.

Our approach differs from those by taking the allocation of emission allowances and targets set by the EU institutions as given and investigating the policy outcome using different equity criteria. Also with a focus on outcomes, fairness in EU climate policy has earlier been evaluated by Marklund and Samakovlis (2007), who show that equity and cost-efficiency both explain the EU burden-sharing agreement under the Kyoto Protocol. Fei et al. (2011), who analyze international equity by studying the historical cumulative emissions per capita, and evaluating those using Gini-coefficients. This paper also adds to the literature by the inclusion of stochastic and deterministic forest sequestration as an abatement option.

Our calculations show that the Gini-coefficients for the current policy are equal to or below the Gini-coefficient for income in the EU member states. When including uncertain sequestration, Gini-coefficients are larger, i.e. the distribution is less fair, but are still below the Gini-coefficient for income for many of the equity criteria. In a third scenario, where sequestration is treated as certain, Gini-coefficients are above that of the income distribution except for the *egalitarian* criterion, i.e. the distribution is relatively unfair. The size of Gini-coefficients varies between equity criteria, and the *egalitarian* criterion gives a lower coefficient than other criteria in all three scenarios. This criterion gives extreme results also in Rose et al. (1998), as noted above.

This paper is organized as follows: first, we describe different theories of justice and how they can be interpreted as different equity principles and operationalized as equity criteria. Next, we present allocations of costs and emissions for different countries under cost-efficient solutions. This is followed by the calculation and analysis of six alternative operative equity criteria. The paper ends with a discussion and conclusions.

2. Theories of justice, equity principles and methods for measuring equity

Three different theories of justice which form a basis for analyzing equity are presented here. These are utilitarianism, Rawlsian, and libertarian theories of justice and they all stem from the philosophical literature (Kverndokk and Rose, 2008). They are global theories centered on society as a whole and are concerned with the compensation of people with relatively low level of income. The theories of justice lay the basis for the most common equity principles that are used in the economic literature. Equity principles are concerned with the normative aspect of distribution of goods and rights, and are here applied to the allocation of costs, abatement and emissions among EU countries. The equity principles give the foundation for the operative criteria used for measuring equity in this paper.

2.1 Theories of justice

According to utilitarianism, a society is just to the extent that its laws and institutions are set up to promote the greatest overall welfare of its members (Mulgan, 2007). It aims to distribute goods, interpreted in a broad sense, so as to maximize the total utility of the members of this society. For this purpose a utilitarian welfare function, in which all individuals have an equal weight, can be used. Utilitarianism does not explicitly address equity, but the objective of welfare maximization implies a certain distribution as an optimal outcome. In the utilitarian theory, it is the actions that lead to welfare improvements that are central, which means that the ends might justify the means to get there.

Rawls (1971) criticises utilitarianism because he believes that it has no respect for the individual, since a person is not regarded as valuable and worth protecting in his/her own right. Rawls instead proposes three key principles. The first is the principle of *equal liberty*, which is concerned with individual rights. The second is the *difference principle*, which distributes wealth, income, power and authority to the greatest benefit of the disadvantaged. The third is the principle of *fair equality of opportunities,* which requires that individuals with similar skills, abilities and motivation get equal opportunities.

The third philosophical theory of justice is the *libertarian* theory, which states that individual freedom prevails unless others may be harmed as a result (Machan, 2006). This idea has similarities to the Pareto efficiency concept in economics, which says that there is only an improvement in welfare when one or more individuals benefit due to a change in the resource allocation, as long as other persons are at least as well off as before. The difference is the central focus in libertarianism on ensuring that fundamental liberties and rights of individuals are respected in processes and procedures.

The theories of justice can serve as a basis for the development of different equity principles, and operative criteria for measuring equity. However, since theories of justice are broadly defined at the societal level, several theories of justice can be in accordance with one, specific equity principle and vice versa (Kverndokk and Rose, 2008). In the following we develop on earlier work on climate change and equity by discussing links between the theories of justice and the equity principles.

2.2 Equity principles; definitions, measurements, and relations to theories of justice

Some principles, such as the *horizontal* equity principle requiring equal treatment of nations, are easier to link to a specific theory, while others are more difficult such as e.g. the *ability to pay* principle. We apply the principles and associated measurements suggested by Ringius et al. (1998) and Rose et al (1998), which are presented in Table 1 but also develop a new measurement for the *market justice* criterion, which fits our aim to analyze equity on emission trading markets.

Table 1. Equity principles, basic definitions, operative equity criteria and mathematical expression

Equity principle	Basic definition	Operative equity criteria	Mathematical expression[c,d]
Ability to pay	Abatement cost should vary with national economic wellbeing	Abatement costs as a proportion to GDP should be equal across nations[a]	$= \frac{Ab.Cost_{i,2020}^{ETS+NETS}}{GDP_{i,2020}}$
Egalitarian	All people should have an equal right to pollute	Emissions to population should be equal across countries[a,b]	$= \frac{E_{i,2020}^{ETS+NETS}}{Pop_{i,2005}}$
Horizontal	All nations should be treated equally	Net cost to GDP should be equal across countries[a,b]	$= \frac{Net\ Cost_{i,2020}^{ETS+NETS}}{GDP_{i,2020}}$
Market Justice	The market is fair	All countries should face the same MAC[a]	$= \alpha_{i,2020}^{ETS}(MAC^{ETS}) + (1 - \alpha_{i,2020}^{ETS})MAC^{NETS}$
Polluters pay	Nations should carry an abatement burden according to their emissions	Net cost to emissions should be equal across countries[b]	$= \frac{Net\ Cost_{i,2020}^{ETS+NETS}}{E_{i,2005}}$
Sovereignty	All nations have an equal right to pollute and be protected from pollution	All countries should face the same emission reduction target in percentages[a,b]	$= \frac{(E_{i,2020}^{ETS+NETS} - E_{i,2005}^{ETS+NETS})}{E_{i,2005}^{ETS+NETS}}$

[a] Rose et al. (1998), [b] Ringius et al. (1998), [c] Complete equality is achieved when all countries have the same outcome (number) for each measurement. [d] Ab.= abatement cost, E.=Emissions, MAC = Marginal Abatement Cost, ETS and NETS refer to the ETS sector and the non-ETS sector respectively and α^{ETS} is calculated as: $\alpha_{i,2020}^{ETS} = \frac{E.Red._{i,2020}^{ETS}}{Tot\ E.Red._{i,2020}}$

Abatement cost is defined as the total cost for abatement measures within a country. Net cost is defined as the abatement cost at national level plus any gain or loss from trading allowances. Marginal cost is the cost of the last unit of emission reduction. See section 3 for the calculations of these costs.

The first equity principle in Table 1, *ability to pay*, states that the total abatement cost at the national level should be proportional to economic wellbeing. This equity principle is difficult to link with a specific theory of justice. However, it could be linked to the difference principle of Rawls theory of justice, because the criterion implies that poorer countries should have a smaller abatement burden than affluent countries. Poorer countries then have an opportunity to catch up with richer ones. One can also see traces of utilitarianism, since a higher absolute burden carried by the affluent should lead to a higher overall welfare, provided that the utility function is concave.

The *egalitarian* equity principle states that all people are equal and should therefore be entitled to an equal share of the global atmosphere (Ringius et al., 1998; Rose et al., 1998). This implies that each person should be allowed to emit the same amount of emissions regardless of where he or she lives. This principle is not easily linked to a specific theory of justice. It can be associated with Rawls' theory of justice in the sense that the nation with the smallest per capita emissions is given the right to emit more, and benefit from the production associated with these emissions. That should also lead to an overall welfare improvement if the marginal benefit of emissions is larger in countries with small emissions, i.e. the principle can also be linked to utilitarianism.

The *horizontal* equity principle states that all nations should be treated equally. The notion of being treated equally can be linked to the libertarian theory, in which procedures should defend people's or nation's rights. Ringius et al. (1998) and Rose et al. (1998) suggest that this could be interpreted as equity implying equal net cost in proportion to GDP across all countries. This interpretation seems rather linked to utilitarianism and Rawls' theory of justice, with the same arguments as for the *ability to pay* principle.

The *market justice* equity criterion can be associated with the libertarian theory of justice if market transactions can be seen as fair processes or procedures. Rose et al. (1998) suggest an operative criterion implying that countries are allocated allowances according to their willingness to pay for those on the margin. Given that this criterion is not applicable to outcomes, we suggest the use of a new operative criterion, which fits our purposes. The *market justice* criterion is then calculated as the weighted MAC (marginal cost of abatement) in ETS and non-ETS sectors, weighted by the fraction of abatement in the sectors. Complete equality is the achieved when all countries have an equal, sector-weighted MAC, which requires either that there is no non-ETS sector or that MAC in the non-ETS sector is identical across countries.

The *polluters' pay* equity principle states that each country should pay in proportion to its emissions. This principle can, in a straightforward manner, be associated with the utilitarian theory of justice as higher pollution is usually linked to higher income from production and hence, the more affluent countries will pay more. This is the case for CO_2 emissions in Europe; see Table C1-C3 in Appendix C, where the net cost to emissions is generally higher for rich countries. However for other pollutants and other parts of the world, this link need not apply. Given lower marginal utility of consumption in rich countries compared to less affluent countries, this will, in our case, imply higher utility under this principle.

The *sovereignty* equity principle states that each country has a 'basic right' to the atmosphere (Rose et al., 1998). This means that each country should reduce emissions by the same percentage. Implicitly, this presupposes that the initial distribution is fair. This principle is hard to link to one specific theory of justice. It can be associated with utilitarian and Rawls theory of justice, the latter because large emitters must undertake more abatement in absolute terms than small emitters, thereby benefitting the disadvantaged countries, provided that larger emissions are associated with a larger wealth or income. It is thereby also connected to utilitarianism because the allocation of burden is welfare improving for the same reasons as discussed above.

Finally, we note that that EU policy-makers have stated an aim to take GDP per capita into account (European Commission, 2008b), which seems to be closely related to the *horizontal* and *ability to pay* principles, that relate costs to GDP.

2.3 Measuring equity in terms of Lorenz curves and Gini-coefficients

The Gini-coefficient is a well-established method for determining equity in a distribution, most known for its use in measuring equity in income distributions, but also frequently used to analyze the consequences of climate change and climate change policy. According to Yitzhaki (1979), the Gini-coefficient is particularly well suited to a distributional analysis, because it is associated with the relative deprivation theory. According to this theory, perceived deprivation depends on the position of each country relative to other countries and not deprivation in absolute terms.

This means that countries compare and evaluate the outcome of a policy against the outcome for others. This seems relevant to the analysis of politically negotiated agreements on burden-sharing within climate policy (e.g. Groot, 2010; Fei et al. 2011). The wide-spread use and the relevance of relative deprivation motivate the choice of the Gini-coefficient as a measure of inequality in this paper.

The Gini-coefficient is not based on a well-defined value judgement applied to inequality in distributions. On the contrary, the Gini-coefficient can be equal for different distributions, as it is insensitive to where in the distribution deviations can be found. For example, two groups of countries can have the same Gini-coefficient, despite that one group contains relatively many poor and the other relatively many rich, since what matters in the calculations is the absolute difference between the countries within each group. Thereby, it differs from the Atkinson index of inequality, which introduces a parameter, which ranges from zero (indifference to inequality); to infinity (representing the Rawlsian criterion) that evaluates distributions according to the income of the poorest people of society.

The Gini-coefficient is calculated from the Lorenz curve, which was originally a graphical representation of the cumulative proportion of individuals' income, mapped against the corresponding cumulative proportion of these individuals. In this study, the Lorenz curve represents the distribution of a chosen equity criterion. For example, the Lorenz curve for the *egalitarian* criterion shows the cumulative proportion of emissions against the cumulative proportion of the population, see e.g. Groot (2010). Figure 1 shows an example of a Lorenz curve based on the *egalitarian* criterion. The Figure also includes a 45° equity line that depicts a perfectly equal distribution i.e. when all countries have the same outcome under a given equity criterion. The Gini-coefficient is calculated by dividing area A, i.e. the area between the 45° equity line and the Lorenz curve, by area A+B in Figure 1, see Barlan (2010).

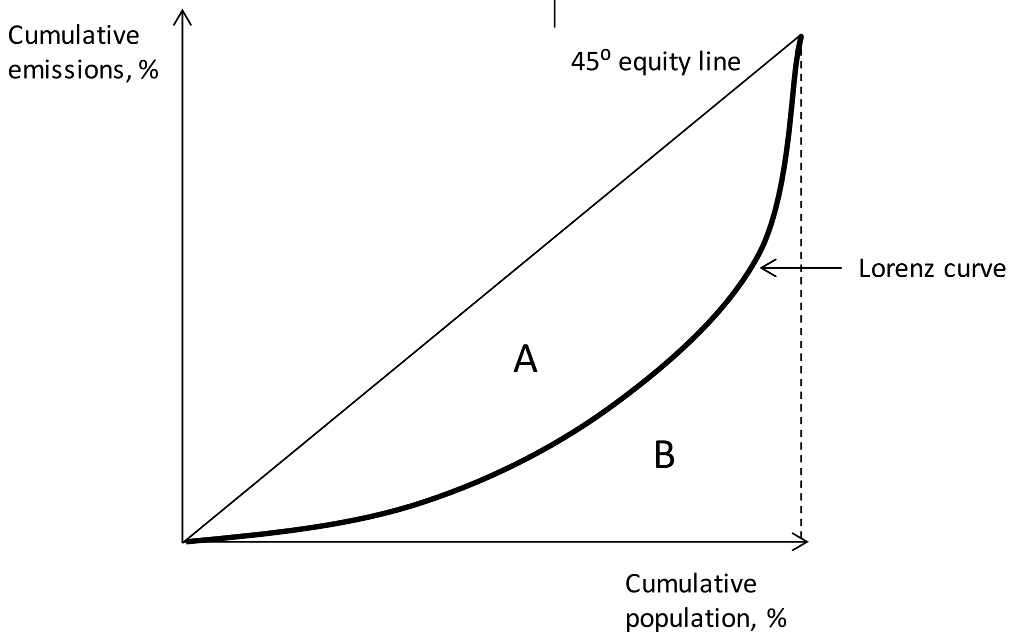

Figure 1. Lorenz curve and equity line

3. Input data for the equity criteria calculations

A non-linear programming model is used to calculate total abatement costs, net costs after trade, marginal costs, and emissions when EU targets are met in a cost-efficient manner. The model covers all 27 EU member states and includes two abatement options; reductions in fossil fuel consumption and sequestration in forests (Gren et al., 2009)[1]. Cost for reductions in fossil fuels in the ETS and non-ETS sectors are calculated as decreases in consumer surplus[2], for three types of fuel; oil (heavy fuel oil, light fuel oil/heating oil, gasoline, diesel and jet kerosene), coal (hard coal and lignite) and natural gas. For each type of fossil fuel, we distinguish between the ETS and non-ETS sectors, where the ETS sector includes heavy energy-using installations, manufacturing industry and parts of the aviation sector and the non-ETS sector includes other industries, households and transportation. Total abatement cost is then determined by the reductions made across all fuel types in these two sectors. Carbon dioxide emissions are calculated using emission coefficients for each type of fossil fuel.

The model also includes carbon sequestration in soils and vegetation on forest land. Sequestration per unit of forest land is determined by an emission coefficient which is associated with uncertainty, measured as the coefficient of variation, see Appendix A Table A1. The uncertainty arises from weather-driven variability in biological processes, and land heterogeneity in combination with uncertainties in land use data (Gren et al., 2009). Uncertainty about the carbon content of fossil fuels could, hypothetically play a similar role for decision makers, but has a negligible impact on cost-efficient policies (Gren et al., 2012).

There is no cost associated with the forest sequestration included in our model. This is explained by current forest management practices within the EU, which imply large positive sequestration because only around 60 percent of the annual gross increment is harvested (Eurostat, 2011). Carbon sequestration thus occurs at zero cost, as a by-product of conventional forestry. The cost savings achieved in our model when including sequestration in climate policy is thus also an estimate of the value of this free carbon sequestration[3].

Costs and equity outcomes are compared for three different scenarios: 1) without forest sequestration; 2) with forest sequestration and uncertainty; and 3) with forest sequestration, but without uncertainty. Scenario 1) and 3) are thus deterministic, while scenario 2) is stochastic. To allow for uncertainty, chance-constrained programming is used (Charnes and Cooper, 1963). A probabilistic constraint is introduced, where it is assumed that policy makers want to achieve EU carbon reduction target with, at least, a subjectively chosen probability. This implies that forest sequestration is associated with one advantage, the expected emission reduction achieved through sequestration, and one disadvantage, the uncertainty. The latter implies that larger reduction efforts must be implemented when the policy-maker dislikes uncertainty compared to when the he or she is indifferent to uncertainty. Policy makers thus face a trade-off between low costs and high reliability in target achievement. For scenario 2), it is assumed that the EU CO_2 reduction targets should be achieved with a 90 percent probability, which is the reliability level also chosen by Gren et al. (2012).

Table 2 and Table 3 show the results of scenario 1) and 2), that are used in the equity criteria calculations. The results of scenario 3) can be found in Appendix B, Table B2. Additional data, necessary to calculate the equity criteria, can be found in Appendix B, Table B1. Table 2 shows the MAC in the non-ETS sector in the scenario with and without sequestration. The large variation between countries is due to differences in abatement cost functions and national targets. In the scenario with sequestration, the MAC is either equal or lower than in the scenario without sequestration, as sequestration is costless. The largest MAC reduction occurs in Latvia, followed by Sweden, Hungary and Slovenia, which is due these countries having large forest areas, high sequestration and low uncertainty. Nine countries have the same marginal cost with and without sequestration, and the explanation is the opposite: small forest areas, low sequestration and high uncertainty, implying that forest sequestration is not included as an abatement option.

In the ETS sector, the MAC is 29€/ton CO_2 without and 24€/ton CO_2 with sequestration, which is below the MAC in the non-ETS sector except for Austria, Finland, Germany, Lithuania, Malta and Sweden. The reason for a higher MAC in the non-ETS sector is stringent national targets and no trade of allowances across countries. The MAC in the ETS sector in the scenario without sequestration can be compared to the current allowance price on the ETS market, which is approximately 4 €/ton CO_2 (Point Carbon, 2013). Although our result is much higher than the current price, it is in line with results from earlier studies, e.g. Capros et al. (2008) and Stankeviciute et al. (2007).

Table 2. MAC and abatement costs in the cost-efficient solutions with and without forest sequestration and when the probability of achieving the EU targets is set at 0.9.

	MAC w/o seq.	**MAC with seq.**	**Abatement cost w/o seq.**	**Abatement cost with seq.**
Unit	*€/ton CO_2 (PPP adj.)*	*€/ton CO_2 (PPP adj.)*	*Million Euro*	*Million Euro*
Austria	144	22	945	72
Belgium	128	112	1247	934
Bulgaria	215	215	278	257
Cyprus	62	62	16	14
Czech Rep.	95	40	412	246
Denmark	185	130	680	355
Estonia	184	39	120	59
Finland	83	20	301	96
France	112	68	2765	1003
Germany	132	22	6104	1455
Greece	70	70	368	326
Hungary	324	107	677	242
Ireland	123	123	555	551
Italy	153	112	5787	3459
Latvia	828	45	424	15
Lithuania	13	13	12	8
Luxembourg	138	138	241	240
Malta	6	6	2	2
Netherlands	37	37	1357	1306
Poland	147	41	1785	1028
Portugal	90	36	326	128
Romania	260	260	1095	1063
Slovakia	312	228	579	229
Slovenia	207	31	228	41
Spain	194	100	3569	1324
Sweden	311	19	2336	38
United Kingdom	159	121	4999	3019

Table 2 shows that abatement costs are lower when sequestration is included, except for Malta. The total cost is reduced by 53 percent. Again, Latvia, Sweden, Hungary and Slovenia have the highest cost reductions, and the reasons for this are the same as for the change in the MAC. However, countries can also have a higher than average reduction in abatement cost when sequestration is included, even if they have a lower than average reduction in the marginal cost, and *vice versa*. Examples of such countries are, in this case, the Czech republic, where MAC is reduced more than the average, whereas total abatement costs are not, and Denmark, where the opposite is the case. Countries with low marginal costs can have stringent national target and also, will carry out more of the abatement within the ETS, implying that the total cost can be high, and *vice versa*. The relationship between MAC and total abatement cost can change to different degree when sequestration is included depending on the shape and location of cost functions.

Table 3 shows the net cost, which is the sum of abatement costs and net gains from allowance trading, for all countries with and without sequestration. The net cost varies between countries for the same reasons as explained above, but is also determined by the allocation of emission allowances. France, Germany, Italy, Spain and the United Kingdom have the highest net cost in both scenarios. These are also the countries with the highest GDP (see Appendix B, Table B1) and therefore have are a larger national abatement burden as well as fewer emission allowances.

Table 3. Net costs and net emissions in the cost-efficient solutions with and without forest sequestration and when the probability of achieving the EU targets is set at 0.9.

	Net cost w/o seq.	**Net cost with seq.**	**Emissions 2020 w/o seq.**	**Emissions 2020 with seq.**
Unit	*Million Euro*	*Million Euro*	*Thousand ton CO_2*	*Thousand ton CO_2*
Austria	989	128	64172	51572
Belgium	1089	821	95122	95687
Bulgaria	83	115	35960	28965
Cyprus	12	13	6735	6803
Czech Rep.	227	185	87174	88472
Denmark	770	458	37473	37898
Estonia	42	-3	11668	8300
Finland	399	211	43840	13949
France	2813	1098	330060	264670
Germany	7224	2752	626800	609300
Greece	367	364	82790	80185
Hungary	580	170	49121	47232
Ireland	622	609	39403	38451
Italy	6346	4054	417980	329000
Latvia	366	-30	7224	-13260
Lithuania	-82	-66	10589	3305
Luxembourg	237	237	10694	10753
Malta	2	2	2235	2262
Netherlands	1505	1460	155840	155280
Poland	991	562	230650	191440
Portugal	318	127	59808	55784
Romania	383	500	82620	35471
Slovakia	413	98	31931	30620
Slovenia	227	41	13000	9547
Spain	3503	1350	303970	288050
Sweden	2290	9	45360	25362
United Kingdom	5709	3854	451530	457680

The inclusion of sequestration generally reduces the net cost except for Bulgaria, Cyprus and Romania. The reason is reduced gain from allowance trading in these three countries. The allowance price in the ETS sector falls when sequestration is included. Then countries which are net sellers both before and after the inclusion of sequestration, and do not substantially increase their sales, gain less from allowance trading. The countries that experience the highest cost saving by including sequestration are Austria, Estonia, Latvia, Slovenia and Sweden. This is partly the same countries as those where marginal and total abatement costs fall, but the inclusion of net gains from allowance trading implies that e.g. Estonia is comparatively better off when net costs are compared than if we look only at abatement costs. This is because Estonia substantially increases its sales of emission allowances.

Table 3 also shows cost-efficient emissions in 2020 with and without sequestration. When sequestration is included, the emission level is higher in Belgium, Cyprus, Czech Republic, Denmark, Luxemburg, Malta and the United Kingdom than in the scenario without sequestration. The reason is that national targets can be reached with smaller reductions in fossil fuels than would otherwise be the case, and that the lower allowance prices implies that for high-cost countries, increased purchases of allowances can be beneficial compared to domestic reductions. Altogether, the total emission level is reduced by 11.4 percent when including carbon sequestration.

The result of the scenario with sequestration but without uncertainty is found in Appendix B, Table B2. In short, both the MACs and the abatement costs are reduced, or equal for four countries, compared with the scenario with sequestration and uncertainty. With certain sequestration, one ton of CO_2 sequestered in forests is equivalent to one ton due to fossil fuel reductions, whereas under uncertainty one ton of CO_2 sequestered in forests is valued less than one ton due to fossil fuel reductions. Net costs are lower in the deterministic scenario for most countries due to the lower abatement costs and smaller purchases of allowances for net buyers. The allowance price in the ETS sector falls to 11€/ton CO_2. For Estonia, Latvia and Lithuania, net costs increase because of the smaller demand for allowance permits in combination with the lower price which reduces their net gains from trading. Emissions are higher in all countries in the deterministic scenario compared to the stochastic scenario, as there are no extra emission reductions undertaken with a purpose to provide a safety-margin with regard to target achievement.

4. Results from the equity assessment

In order to assess the equity in EU's burden-sharing scheme, the six equity criteria in Table 1 have been calculated for the three scenarios mentioned above. In the following, Lorenz curves and Gini-coefficients for different criteria and scenarios are presented. Due to the similarity with the stated aims of the EU burden allocation, we first discuss the *horizontal* and *ability to pay* criteria.

Figure 2 shows the Lorenz curve for the *horizontal* equity criterion. Closest to the 45° equity line is the Lorenz curve for the case without sequestration, followed by that for the scenario with sequestration and uncertainty and the one with sequestration, but no uncertainty. The distribution is thus more unequal when sequestration is included and the most unequal in the deterministic sequestration scenario. Equality changes when sequestration is included because there is a large variation in forest area and per hectare sequestration, implying that the gains from inclusion of sequestration are unevenly distributed. The effect on distribution of the *horizontal* equity criterion is determined by whether this leads to a more similar or more different distribution of net costs compared to the distribution of GDP. In the scenario with sequestration and uncertainty, the net cost to GDP will fall more for countries with low sequestration uncertainty than for countries with high uncertainty, compared to the scenario where sequestration is not included.

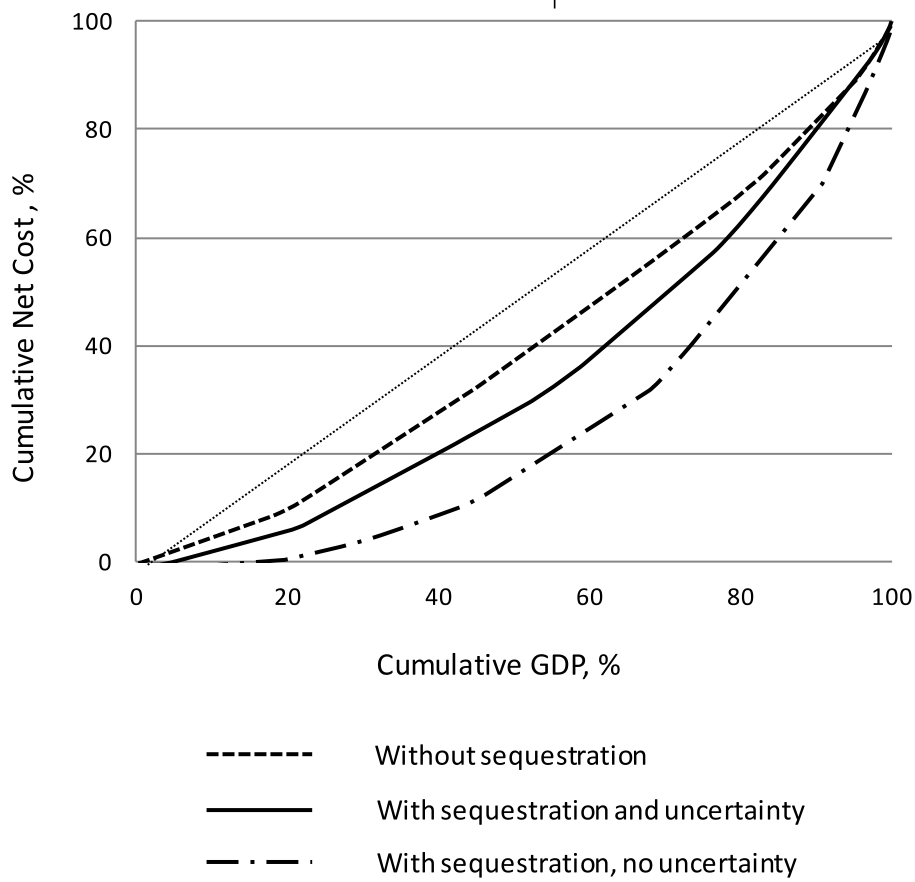

Figure 2. Lorenz curves for the horizontal equity criterion i.e. net cost in relation to GDP.

Calculations of the correlation coefficient for forest land and GDP based on data in Tables A1 and B1 in the respective appendices give a value of 0.72. This suggests that wealthier countries will benefit more from inclusion of sequestration than poor countries. Uncertainty in carbon sequestration and GDP could be positively correlated if uncertainty is to large extent determined by the quality and quantity of forest statistics and land mapping, given that both can be resource demanding. The estimated correlation coefficient between GDP and the coefficient of variation of carbon sequestration is however only -0.20, implying that there is no strong relationship between these two factors. The results show no clear pattern with regards to groups of countries benefitting from the inclusion of sequestration.

The distribution of the *ability to pay* criterion results in the same ranking of scenarios with regard to equity as the *horizontal*, see Figure 3. However, the magnitude of the difference between scenarios increases, as shown by the Lorenz curves. The explanation for this is that allowance trading leads to a dispersal of the benefits of sequestration among all involved countries. It is well known that allowance trading is beneficial due to the potential to lower cost compared the use of separate, national targets, and because equity can be dealt with through the initial distribution of allowances. Our results suggest that emission trading systems already in place can serve as a buffer against inequality, when new cheap abatement measures are introduced.

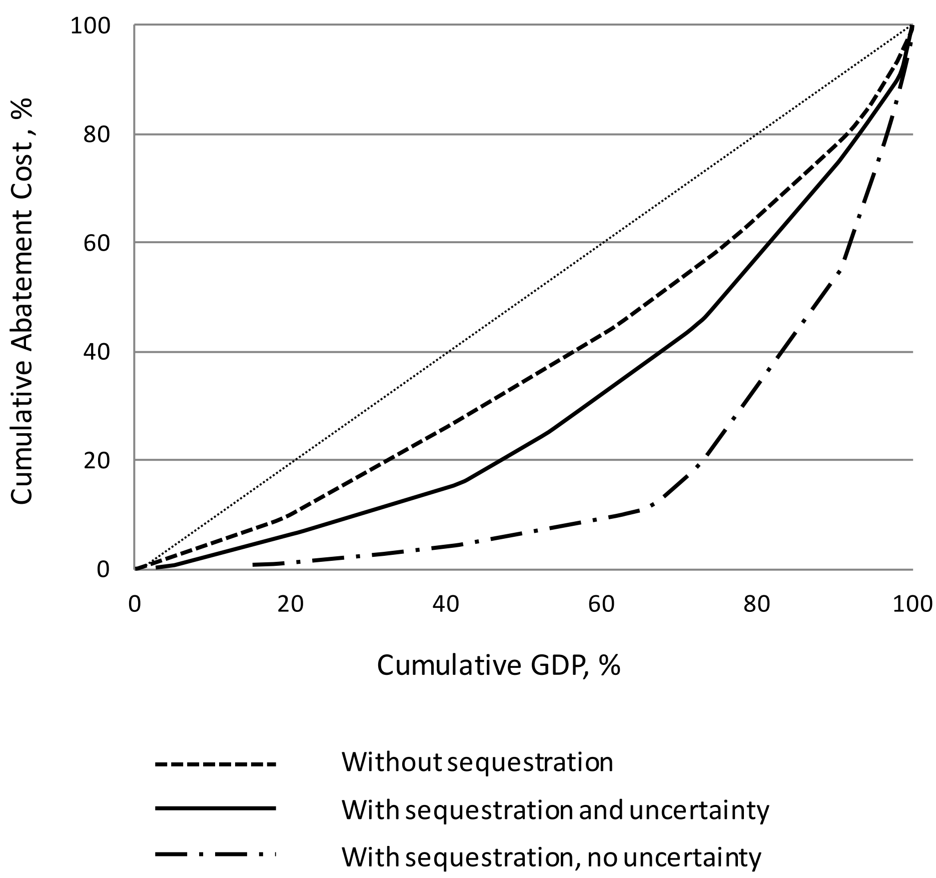

Figure 3. Lorenz curves for the ability to pay equity criterion i.e. abatement cost to GDP.

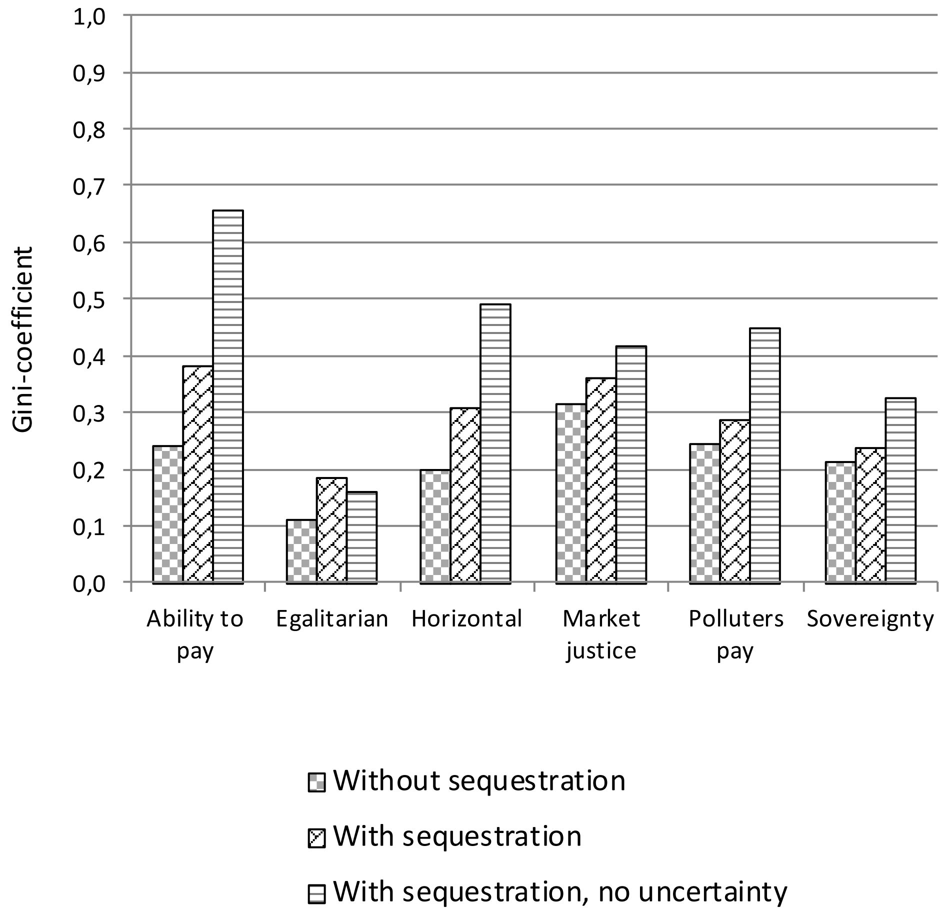

Figure 4. Gini-coefficients for all six equity criteria

Gini-coefficients are calculated for all six equity criteria. Figure 4 shows that Gini-coefficients range between 0.11-0.32 without sequestration, 0.19-0.38 with sequestration and uncertainty and 0.16-0.66 with sequestration, but without uncertainty. Inequality increases with the inclusion of sequestration, more in the deterministic scenario than in the probabilistic one, except for the *egalitarian* equity criterion. The larger inequality in the deterministic scenario is explained by the certain sequestration potential being more valuable than the uncertain potential, in combination with the unequal distribution of forest area.

Gini-coefficients for the *egalitarian* criterion are low compared to those for other criteria due to the strong correlation between countries population size and emissions. This criterion differs from the others in that the distribution is more equal under deterministic sequestration than under probabilistic. The reason is that forest sequestration is more or less uncorrelated with population wherefore equality is reduced when including sequestration. The impact of forest sequestration on emissions levels is larger in the probabilistic scenario as larger reductions need to be undertaken in order to comply with targets, which explains the larger inequality in the probabilistic scenario compared to the deterministic.

Results can be compared with the average Gini-coefficient for the income distribution, which equaled 0.31 in 2011 (Eurostat, 2013). In the scenario without sequestration, all Gini-coefficients calculated here are lower than that for income, except for the *market justice* criterion where it is just above. In the scenario with sequestration under uncertainty, four out of six equity criteria give Gini-coefficients below that for the income distribution, whereas in the scenario with deterministic sequestration, all Gini-coefficients but one are above that for the income.

5. Discussion and conclusion

We evaluate equity in the outcome of cost-efficient EU climate policies to 2020, comparing three different scenarios; 1) when targets can only be met through fossil fuel reductions, 2) when uncertain carbon sequestration is added as an abatement option, and 3) when sequestration is included but treated as certain. Results show that there is a trade-off between lower costs and increased inequality when including sequestration. The abatement costs are reduced by 53% in the scenario with stochastic sequestration and 85% in the scenario with deterministic sequestration, compared to the scenario without sequestration.

To evaluate the equity in the burden-sharing, six different equity criteria were applied to the outcomes of cost effective solutions. With stochastic sequestration, Gini-coefficients increase by 11-65 percent, and with deterministic sequestration by 32-173 percent. The inclusion of sequestration thus leads to larger disparities among countries. Yet with stochastic sequestration, most Gini-coefficients are below that for the income distribution within the EU. When sequestration is treated as certain inequality increases further as sequestration is assigned a higher value with regard to compliance with targets, compared to when it is treated as uncertain. The impact on policy outcomes is therefore larger.

An interesting result is that the presence of international emission trading seems to be a buffer against negative equity consequences from the introduction of a new, low-cost abatement option such as sequestration. This buffering effect is explained by the benefits from sequestration being dispersed among countries through the impact on allowance demand and supply.

Comparing our results with those of Rose et al. (1998), our study confirms that the *sovereignty* and *horizontal* criteria give comparable outcomes. In their study, these two criteria result in similar net costs of mitigation, whereas in our case, the criteria give comparable Gini-coefficients in the scenario without sequestration. Both studies find the *egalitarian* criterion to give quite different results than other criteria. Rose et al. (1998) find that under this criterion, all industrialised countries are buyers and all developing countries sellers of allowances, leading to a net gain for developing countries. We show that the *egalitarian* criterion gives substantially lower Gini-coefficients than other criteria.

The stated aim of the European Commission (2008b), when proposing the burden-sharing, was to ensure that efforts and costs were distributed in an equitable manner and that accelerated growth in less wealthy countries was allowed for. Our results show that both the magnitude and direction of change in Gini-coefficients when policies are adjusted depend on the choice of equity criterion. It is therefore important to thoroughly evaluate the choice of criteria to use, when equity criteria are used as inputs in the policy process, given that there no generally accepted definition of equity. Moreover, criteria which measure the inequality in the overall distribution of outcomes need to be supplemented with an analysis of outcomes for individual countries as well as groups of countries, even though in our case, results do not show any clear pattern with regards to groups of countries.

The burden sharing as well as the allocation of allowances within the EU has undergone revisions over time. Whereas we note that the introduction of a new, low-cost abatement option such as sequestration can have a negative impact on equity, such impacts can be reduced in connection with a revision of targets or allocation of allowances, e.g. through increasing the number of allowances to countries that are disadvantaged from the introduction of sequestration.

It should also be noted that whereas increased sequestration can have substantial benefits for climate policy, it could also affect other ecosystem services provided by forests such as, e.g., biodiversity. Such side-effects from sequestration are not dealt with in our paper but can be important for policy choices. Further limitations of the study are the static perspective, and the inclusion of only two kinds of abatement options. Inclusion of additional abatement options, such as renewable energy and carbon sequestration in the agricultural sector, could affect the results. Furthermore, the study only includes carbon sequestration as a by-product of current forest management and inclusion of measures to increase sequestration through changes in land use, and forest and agricultural practice, could also affect conclusions. Results should therefore be interpreted with care.

Footnotes

[1] Other abatement options such as renewable energies, carbon capture and storage (CCS) and agricultural sequestration are currently not part of the model. The limited number of abatement options can imply that the estimated MAC is higher than if cheap, additional options were included. However, many renewable energy sources such as wind power and solar energy, as well as CCS are associated with considerable costs, wherefore it is at least not obvious that they would be included in a cost-efficient solution.

[2] Consumer surplus is represented by the area below the demand function and above the price line. Energy efficiency is indirectly taken into account in the cost functions as the possibility of energy efficiency improvements affects fossil fuel demand elasticities.

[3] This value could be reduced if demand for, e.g., bioenergy or timber changes due to political decisions or changes in demand. Measures to increase sequestration are not included in the model, but could be an interesting subject for further research.

Appendix A

Table A1. Member states forest area, emission factors and uncertainties

				Emission factor: Net CO2		
	Total forest area	Mineral soil	Organic soil	Mineral soil	Organic soil	Uncertainty[b]
Country	*1000 ha*[a]	*1000 ha*[a]	*1000 ha*[a]	*Mg C/ha*	*Mg C/ha*	*Coefficient of variation*
Austria	3620	3620		-1.49	-1.35	0.30
Belgium	621	621		-1.22	-1.18	0.10
Bulgaria	4076	4076		-0.47	-0.47	0.80
Cyprus	1	1		-	-	0.80
Czech Republic	2593	2574	19	-0.48	-0.48	0.30
Denmark	476	458	18	-1.58	-1.57	0.28
Estonia	2252	1480	772	-0.81	0.28	0.37
Finland	22146	16105	6041	-0.61	-0.22	0.37
France	16384	16384		-1.41	-1.36	0.58
Germany	10799	10799		-2.00	-2.00	0.30
Greece	6560	6560		-0.18	-0.18	0.80
Hungary	1806	1806		-0.70	-0.70	0.30
Ireland	554	543	11	-0.56	3.25	1.04
Italy	11261	11261		-2.30	-1.28	0.62
Latvia	2929	2929		-1.67	-1.67	0.30
Lithuania	2030	2030		-1.14	-1.14	0.30
Luxemburg	1	1		-	-	0.67
Malta	1	1		-	-	0.62
Netherlands	479	479		-1.43	-1.43	0.67
Poland	8991	8752	239	-1.66	-1.22	0.30
Portugal	3476	3476		-0.48	-0.46	0.40
Romania	6755	6755		-1.51	-1.51	0.80
Slovakia	1932	1927	5	-0.44	-0.44	0.80
Slovenia	1174	1174		-1.10	-1.10	0.80
Spain	14191	14191		-0.64	-0.64	0.40
Sweden	25501	23235	2266	-0.36	0.15	0.20
United Kingdom	2229	2229		-1.64	-1.91	0.23
Total	152836.57					

Source: UNFCCC, 2009

[a] Note that Cyprus, Malta and Luxemburg have not reported any forest area or emission factors, therefore assumed to be 1.

[b] With regard to uncertainty, the following countries are assumed to have the same uncertainty as Greece: Bulgaria, Cyprus, Romania, Slovakia, Slovenia. The same as Austria: Poland, Latvia, Lithuania, Hungary, Germany, Czech Republic. The same as Finland: Estonia. The same as Portugal: Malta, Spain. The same as Netherlands: Luxemburg.

Appendix B

Table B1. Non-ETS targets, total emissions, GDP and population

	Non-ETS targets	Total emissions 2005	GDP 2020	Population 2005
Units	*%*	*Thousand ton CO2*	*Million €uro*	*Total*
Austria	-16	73700	310400	8201359
Belgium	-15	107800	389500	10445852
Bulgaria	20	45100	34700	7761049
Cyprus	-5	7400	22500	749175
Czech Republic	9	114800	154200	10220577
Denmark	-20	48900	245900	5411405
Estonia	11	15200	15400	1347510
Finland	-16	54100	201400	5236611
France	-14	378400	2144400	62772870
Germany	-14	804800	2723600	82500849
Greece	-4	96200	290600	11082751
Hungary	10	55000	114800	10097549
Ireland	-20	45700	221700	4109173
Italy	-13	451000	1678700	58462375
Latvia	17	7300	17400	2306434
Lithuania	15	12600	30300	3425324
Luxembourg	-20	12400	47300	461230
Malta	5	3000	6800	402668
Netherlands	-16	171600	637900	16305526
Poland	14	290700	406100	38173835
Portugal	1	61600	179600	10529255
Romania	19	89700	135000	21658528
Slovakia	13	37100	73300	5384822
Slovenia	4	15200	44000	1997590
Spain	-10	339400	1285200	43038035
Sweden	-17	48500	380300	9011392
United Kingdom	-16	559700	2373000	60059900

Source: Member states targets can be found in Directive 406/2009/EC. Emissions and Population are from Eurostat and GDP forecast from European Commission, 2009.

Table B2. Marginal cost, abatement cost, net cost and emissions in 2020 in the deterministic scenario with sequestration

	MAC	**Abatement cost**	**Net cost**	**Emissions 2020**
Unit	*€/ton CO_2 (PPP adjusted)*	*Million Euro*	*Million Euro*	*Thousand ton CO_2*
Austria	10	14	63	54942
Belgium	109	852	821	98278
Bulgaria	29	31	37	38567
Cyprus	62	11	12	6980
Czech Republic	18	49	128	100030
Denmark	95	164	245	42078
Estonia	18	12	12	11086
Finland	9	19	111	18457
France	10	42	141	290310
Germany	10	287	1511	677660
Greece	15	39	133	91907
Hungary	54	61	64	53121
Ireland	90	368	417	41699
Italy	10	90	512	390980
Latvia	21	3	-12	-12560
Lithuania	13	2	-28	3686
Luxembourg	138	237	237	10913
Malta	6	0	1	2333
Netherlands	34	1074	1180	161110
Poland	19	204	405	239710
Portugal	12	23	68	61642
Romania	23	62	-73	60168
Slovakia	42	25	3	36396
Slovenia	14	8	26	11486
Spain	12	87	283	323600
Sweden	9	8	5	27148
United Kingdom	103	1876	2548	492050

Appendix C

Table C1. Equity criteria results without sequestration

Equity criteria	**Ab. to pay**	**Egalitarian**	**Horizontal**	**Mkt. Justice**	**Polluters Pay**	**Sovereignty**
Equity measure	Ab. Cost/GDP	Emission /Population	Net Cost/GDP	MAC (PPP adj.)	Net cost (PPP adj.)/emission	Emission reduction
Unit	*%*	*ton CO_2/capita*	*%*	*€/ton CO_2*	*€/ton CO_2*	*%*
Austria	0.305	7.8	0.319	95.9	12.4	12.9
Belgium	0.320	9.1	0.279	93.7	9.0	11.8
Bulgaria	0.800	4.6	0.241	172.0	4.9	20.3
Cyprus	0.071	9.0	0.055	49.6	1.9	9.0
Czech Republic	0.267	8.5	0.148	61.2	3.3	24.1
Denmark	0.277	6.9	0.313	61.9	11.1	23.4
Estonia	0.781	8.7	0.274	92.1	4.5	23.2
Finland	0.150	8.4	0.198	36.0	6.0	19.0
France	0.129	5.3	0.131	78.2	6.5	12.8
Germany	0.224	7.6	0.265	52.4	8.1	22.1
Greece	0.127	7.5	0.126	45.6	4.4	13.9
Hungary	0.590	4.9	0.505	289.8	16.4	10.7
Ireland	0.250	9.6	0.280	72.4	10.7	13.8
Italy	0.345	7.1	0.378	101.0	12.9	7.3
Latvia	2.439	3.1	2.102	1193.9	94.0	1.0
Lithuania	0.040	3.1	-0.271	51.5	-12.2	16.0
Luxemburg	0.510	23.2	0.500	110.6	16.7	13.8
Malta	0.033	5.6	0.033	39.8	1.0	25.5
Netherlands	0.213	9.6	0.236	14.7	3.7	9.2
Poland	0.440	6.0	0.244	98.6	5.8	20.7
Portugal	0.182	5.7	0.177	60.6	5.9	2.9
Romania	0.811	3.8	0.284	230.4	8.8	7.9
Slovakia	0.790	5.9	0.563	234.1	20.1	13.9
Slovenia	0.519	6.5	0.515	141.1	19.6	14.5
Spain	0.278	7.1	0.273	114.4	10.8	10.4
Sweden	0.614	5.0	0.602	213.7	38.1	6.5
United Kingdom	0.211	7.5	0.241	69.6	8.6	19.3
Mean	0.434	7.3	0.334	143.5	12.3	14.3
Gini Coeff.	0.241	0.112	0.200	0.315	0.245	0.215

Table C2. Equity criteria results with sequestration and uncertainty

Equity criteria	**Ab. to pay**	**Egalitarian**	**Horizontal**	**Mkt Justice**	**Polluter Pay**	**Sovereignty**
Equity measure	Abatement Cost/GDP	Emission /Population	Net Cost/GDP	MAC (PPP adj.)	Net cost (PPP adj.)/emission	Emission reduction
Unit	*%*	*ton CO_2/capita*	*%*	*€/ton CO_2*	*€/ton CO_2*	*%*
Austria	0.023	6.3	0.041	21.7	1.6	30.0
Belgium	0.240	9.2	0.211	82.5	6.8	11.2
Bulgaria	0.740	3.7	0.330	166.6	6.7	35.8
Cyprus	0.063	9.1	0.057	48.8	1.9	8.1
Czech Republic	0.160	8.7	0.120	41.9	2.7	22.9
Denmark	0.144	7.0	0.186	42.4	6.6	22.5
Estonia	0.384	6.2	-0.019	39.9	-0.3	45.4
Finland	0.048	2.7	0.105	19.3	3.2	74.2
France	0.047	4.2	0.051	46.5	2.5	30.1
Germany	0.053	7.4	0.101	21.5	3.1	24.3
Greece	0.112	7.2	0.125	42.7	4.3	16.6
Hungary	0.210	4.7	0.148	91.3	4.8	14.1
Ireland	0.249	9.4	0.275	71.7	10.5	15.9
Italy	0.206	5.6	0.242	73.3	8.3	27.1
Latvia	0.086	-5.7	-0.170	58.1	-7.6	281.6
Lithuania	0.028	1.0	-0.219	42.7	-9.9	73.8
Luxemburg	0.507	23.3	0.501	111.9	16.7	13.3
Malta	0.022	5.6	0.032	32.9	1.0	24.6
Netherlands	0.205	9.5	0.229	14.4	3.6	9.5
Poland	0.253	5.0	0.138	45.8	3.3	34.1
Portugal	0.071	5.3	0.071	30.2	2.3	9.4
Romania	0.787	1.6	0.370	229.7	11.4	60.5
Slovakia	0.313	5.7	0.134	123.3	4.8	17.5
Slovenia	0.093	4.8	0.093	32.4	3.5	37.2
Spain	0.103	6.7	0.105	54.1	4.2	15.1
Sweden	0.010	2.8	0.002	18.2	0.2	47.7
United Kingdom	0.127	7.6	0.162	52.4	5.8	18.2
Mean	0.196	6.1	0.127	61.3	3.8	37.8
Gini Coeff.	0.384	0.185	0.309	0.360	0.288	0.239

Table C3. Equity criteria results with sequestration, without uncertainty

Equity criteria	**Ab. to pay**	**Egalitarian**	**Horizontal**	**Mkt Justice**	**Polluters Pay**	**Sovereignty**
Equity measure	Abatement Cost/GDP	Emission /Population	Net Cost/GDP	MAC (PPP adj.)	Net cost (PPP adj.)/Emissions	Emission reduction
Unit	*%*	*ton CO_2/capita*	*%*	*€/ton CO_2*	*€/ton CO_2*	*%*
Austria	0.005	6.7	0.020	9.9	0.8	25.5
Belgium	0.219	9.4	0.211	87.9	6.8	8.8
Bulgaria	0.090	5.0	0.108	33.3	2.2	14.5
Cyprus	0.050	9.3	0.055	52.5	1.8	5.7
Czech Republic	0.032	9.8	0.083	19.2	1.9	12.9
Denmark	0.067	7.8	0.100	35.0	3.5	14.0
Estonia	0.079	8.2	0.078	18.3	1.3	27.1
Finland	0.009	3.5	0.055	8.8	1.7	65.9
France	0.002	4.6	0.007	9.1	0.3	23.3
Germany	0.011	8.2	0.055	9.8	1.7	15.8
Greece	0.013	8.3	0.046	13.3	1.6	4.5
Hungary	0.053	5.3	0.056	47.3	1.8	3.4
Ireland	0.166	10.1	0.188	58.0	7.2	8.8
Italy	0.005	6.7	0.030	9.9	1.0	13.3
Latvia	0.017	1.6	-0.071	26.6	-3.2	49.5
Lithuania	0.006	-3.7	-0.092	21.4	-4.1	199.7
Luxemburg	0.501	23.7	0.501	116.3	16.7	12.0
Malta	0.004	5.8	0.020	15.0	0.6	22.2
Netherlands	0.168	9.9	0.185	13.2	2.9	6.1
Poland	0.050	6.3	0.100	21.0	2.4	17.5
Portugal	0.013	5.9	0.038	12.8	1.3	-0.1
Romania	0.046	2.8	-0.054	24.1	-1.7	32.9
Slovakia	0.034	6.8	0.004	26.8	0.1	1.9
Slovenia	0.019	5.7	0.059	14.8	2.3	24.4
Spain	0.007	7.5	0.022	11.6	0.9	4.7
Sweden	0.002	3.0	0.001	8.3	0.1	44.0
United Kingdom	0.079	8.2	0.107	52.5	3.9	12.1
Mean	0.065	6.9	0.071	28.8	2.1	24.8
Gini Coeff.	0.657	0.161	0.492	0.416	0.448	0.326

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