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Using benchmarking for the primary allocation of EU allowances – An application to the German power sector

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Abstract

Basing allocation of allowances for existing installations under the EU Emissions Trading Scheme on specific emission values (benchmarks) rather than on historic emissions may have several advantages. Benchmarking may recognize early action, provide higher incentives for replacing old installations and result in fewer distortions in case of updating, facilitate EU-wide harmonization of allocation rules or allow for simplified and more efficient closure rules. Applying an optimization model for the German power sector, we analyze the distributional effects of various allocation regimes across and within different generation technologies. Results illustrate that regimes with a single uniform benchmark for all fuels or with a single benchmark for coal- and lignite-fired plants imply substantial distributional effects. In particular, lignite- and old coal-fired plants would be made worse off. Under a regime with fuel-specific benchmarks for gas, coal, and lignite 50 % of the gas-fired plants and 4 % of the lignite and coal-fired plants would face an allowance deficit of at least 10 %, while primarily modern lignite-fired plants would benefit. Capping the surplus and shortage of allowances would further moderate the distributional effects, but may tarnish incentives for efficiency improvements and recognition of early action.

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1 Introduction

According to the European Union's Emissions Trading Directive (CEC, 2003), EU Member States have to allocate at least 95 % of all allowances for free in the first trading period (2005-2007) of the European Union Emissions Trading Scheme (EU ETS). In the second phase (2008-2012), this share is 90 %. As in almost all existing emission trading systems (e.g. Boemare and Quirion, 2002), most Member States decided to allocate all the allowances to existing installations for free in the first phase. Typically, allocation was based on the historical levels of emissions in a fairly recent reference period ("conventional grandfathering") (Betz et al., 2004; Buchner et al., 2006; DEHST, 2005; Ecofys, 2004). To calculate the actual number of allowances, historical emissions were multiplied by one or several adjustment factors to account for expected (sectoral) growth, overall future compliance with the Kyoto target and emission savings potentials. Allocating allowances based on historical emissions in a recent reference period implies that companies which had invested in abatement measures prior to that period (early action) would receive fewer allowances than companies which had not invested in such measures. The latter companies would then have an unfair advantage, able to reduce emissions at lower cost and sell their extra allowances on the market. To account for this potential disadvantage, some Member States, notably Germany, included special provisions for modern or modernized installations. Specifically, if operators are able to provide evidence that investments (going as far back as 1994) resulted in specific minimum CO_2-intensity improvements, then the allocation to those installations is not reduced by means of an adjustment factor for 12 years after the investment was made. However, these provisions (together with other special allocation rules) also increased the complexity of the EU ETS and resulted in higher transaction costs for companies and the administration. For the second phase, conventional grandfathering remains the dominant allocation method for existing installations (Betz et al., 2006; Schleich et al., 2007).

Alternatively, allocation could also be based on benchmarks, i.e. on specific emission values per unit of production (e. g. kg CO_2/MWh electricity or t CO_2/t cement clinker) for a particular group of products or installations. For example, benchmarks may be based on average specific emission values per unit of production based on the installations in a particular group (average benchmarks), on the best available technology (BAT-benchmarks); or on the top x % performers of the EU or the world. The actual number of allowances can be derived from the specific benchmark value per unit of activity multiplied by historical or predicted production levels, utilization rates or the capacity of the individual installations. If the total number of allowances available to a group of installations is fixed – as is usually the case – then the allocation to an individual installation within that group is independent of the actual benchmark value, ceteris paribus. In general, a benchmarking allocation favours carbon-efficient installations over less carbon-efficient installations, since operators of the latter need to purchase missing allowances on the market or have fewer surplus allowances available. Thus, benchmarking may have substantial distributional implications.[1]

In the first phase of the EU ETS, only a few Member States: France, Italy, the Netherlands, and Sweden have applied benchmarking for allocating EUAs to some existing installations. In the second phase, Austria, Belgium, Germany, Latvia, Spain and the UK among others will also use benchmarking. In both phases, the main application of benchmarking to existing installations is in the energy sector. For example, the revised version of the German NAP (BMU, 2007) foresees fuel-specific benchmarking based on BAT and historical production levels.

In addition, in both phases, many Member States such as Denmark, Germany, the United Kingdom, or Sweden use benchmarking to allocate allowances to new installations from the energy and also several industry sectors.

To limit the distributional effects, differentiated benchmarks are usually applied to account for different fuel inputs, installation size, technologies or products. Differentiated benchmarks may – at least to some extent – be justified for existing installations if there are sunk costs involved because of investments undertaken long before the EU ETS was planned. For new projects, however, differentiated benchmarks amount to technology-specific subsidies, which limit innovation incentives to the sub-groups of benchmarks and lead to losses in overall efficiency.

The power sector is particularly well suited to benchmarking, since its output is fairly homogenous and installations can be easily assigned to benchmarking groups (see among others Radov et al., 2005; STEM, 2006). For example, in the Guidance for National Allocation Plans for the second phase, the European Commission specifically mentions benchmarking as a possible allocation method for existing installations in the electricity sector (CEC, 2005, p. 9).

In this paper we use a regular power market optimization model to explore the distributional implications across and within generation technologies under several benchmarking regimes for existing installations in the German power sector. In

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[1] Distributional effects may occur independently of whether the additional costs from emissions trading can be passed on to customers or not. For empirical analyses of the power sectors' ability to pass on these costs in the context of the EU ETS see, for example, Sijm et al. (2006).

particular, we focus on analysing the effects of uniform average benchmarks and fuel-specific benchmarks. For all regimes, we also consider allocation rules which limit both the under- and over-allocation of EUAs to individual installations (compared to historical emissions). Finally, we explore whether such caps have a significant effect on the total number of allowances to be allocated to the power sector.

Our results suggest that a uniform average benchmark for all gas-, lignite- and coal-fired power plants would be associated with significant distributional effects. All gas-fired and most coal-fired plants would benefit at the expense of most lignite and old coal-fired plants. In total, almost 40 % of the installed capacities would receive an allocation corresponding to a surplus or shortage of allowances (compared to historical emissions) of more than 10 %. This share rises to 25 % if fuel-specific benchmarks for lignite-, coal- and gas-fired plants are applied. An allocation regime with a single benchmark for coal- and lignite-fired plants still results in a shortage of allowances for about 70 % of the lignite-fired plants. The results also show that the distributional effects of benchmarking could be constrained significantly by capping the surplus and/or shortage of allowances. But a cap on over-allocation would also limit recognition of early action, and a cap on under-allocation would result in lower incentives for new investments. Also, if only under-allocation were limited, low cut-off factors could lead to a substantially lower allocation for the non-power installations.

The remainder of the paper is organized as follows. Section 2 provides a brief overview of the rationale for using benchmarks to allocate allowances to existing installations. Section 3 describes the methodology. The results are presented in Section 4 and the conclusions in Section 5.

2 Rationale for using benchmarking

There are various reasons why a benchmarking allocation may be preferable to allocation based on historical emissions. First, since benchmarking favours installations with low emission values and accounts for early action, the allocation outcome may be perceived as “fair”. Benchmarking can also avoid incentive problems arising from asymmetric information, as pointed out by Perry and Toman (2002), when credits from early emission reduction have to be explicitly calculated.

Second, benchmarking provides lower incentives for companies than conventional grandfathering to act strategically in case of “updating” (see also Sterner and Muller, 2006): If the reference period is updated, then companies’ incentives to reduce emissions are distorted because future allocation will be lower. Consequently, the European Commission’s Guidance for National Allocation Plans for the second phase (2008-12), requests "that Member States do not rely on first phase emissions or other first trading period data" for the allocation at installation or sector level (CEC, 2005, p. 8). Unlike conventional grandfathering, allocation under benchmarking is not based on an individual installation’s emission value. As a result, the operators’ incentives to behave strategically to affect the future endowment of EUAs are limited and benchmarking is associated with lower efficiency losses.

Third, if the allocation to new and existing installations is based on identical benchmark rules, closure rules could be simplified and more efficient outcomes achieved. In practice, in the first and second phase, most EU-Member States decided that once an installation is closed or emissions drop below a certain threshold, there should be no further allocation of allowances for the remainder of the period. However, from a purely economic perspective, taking away allowances for closures results in (economic) inefficiencies and disincentives for new investments. If closure leads to an allocation stop, old plants may be operated for too long and new investments postponed, since the opportunity costs of a closure are not accounted for properly. In fact, stopping allocation for closures subsidizes output, since there are too many companies in the market (Spulber, 1985; Graichen and Requate, 2005; Ellerman, 2006). Stopping allocation after closure is also a form of updating, resulting in inefficient outcomes (see also Åhman et al., 2007). Thus, applying identical benchmarking allocation rules to existing and new installations as is the case in France in the first phase provides more efficient economic incentives for closures. However, using identical rules for existing and new installations may also result in undesired distributional effects. If average benchmarks based on the performance of existing installations were used, new installations would clearly benefit and there would have to be a large reserve of allowances kept for free allocation to new entrants. Alternatively, if the benchmarks were based on BAT, this new entrants' reserve could be smaller, but existing installations would be worse off, ceteris paribus. If existing installations simply retained their initial allocation indefinitely, then the incentives for closure and investments in carbon-efficient installations would be optimal from an economic efficiency perspective.[2] In this case, benchmarking and conventional grandfathering would provide identical incentives to existing installations for modernization and investments in more carbon-efficient installations. However, the actual rules applied in the EU ETS lead to a different outcome: closures result in a termination of allocation. In this case, benchmarking provides higher incentives for new investments than conventional grandfathering (see Proposition 1 in Appendix A). As also shown in Appendix A as a corollary, this difference generally depends on the specific emissions of the installation compared to the benchmark value, on the prices for EUAs, on the length of the trading period, and on the level of the adjustment factor. In several Member States allowances may be transferred from closed installations to replacement installations. In this case, benchmarking and conventional grandfathering provide identical incentives to invest in new plants (see Proposition 2 in Appendix A).

Finally, benchmarking facilitates comparison across EU Member States and may be seen as a first step towards harmonized allocation rules throughout the EU (Ecofys, 2006; AEA Technology Environment and Ecofys, 2006; Kruger and Pizer, 2004). Economic theory suggests that new projects should buy allowances at market prices. In this case, investment decisions are then based on the full social costs. Allocating allowances for free to new projects amounts to subsidizing investments (over-capacity) and output (Spulber, 1985; Betz et al., 2004; Ellerman, 2006; Åhman et al., 2007). While the Commission would have preferred newcomers to purchase allowances on the market (e. g. CEC, 2001), in all Member States new projects receive allowances for free from a new entrants' reserve in the first and second phase (Betz et. al., 2006; Schleich et al., 2007). Because Member States may use allocation rules for new installations to attract new investments, changing these rules is likely to require binding coordination to overcome a possible prisoners' dilemma situation.

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[2] For example, in the US EPA Acid Rain program, closure of a plant does not terminate allocation and new projects need to purchase allowances on the market or via auctions. Linking allocation to operators as in the US EPA Acid Rain program would have generated more efficient rules for closures and new entrants in the EU ETS, where allocation is linked to installations instead.

The potential drawbacks of benchmarking include more stringent data requirements, the need to form benchmarking groups (see, for example, Radov et al., 2005) and distributional effects which may cause opposition from those companies who would be worse off under a benchmarking regime than under conventional grandfathering. These distributional effects will be analysed in depth in the following sections for power generation in Germany.

3 Methodology

Since installation-level data on electricity generation and specific emissions is considered confidential by the operators and thereby not available, we use a power market model to analyse the distributional effects of various benchmarking regimes for power generation in Germany. In a first step we model electricity generation by different types of technologies and fuels for a base year. In a second step we analyse different allocation rules based on the model results. More specifically, we apply a multi-period linear (myopic) optimization model for the German power sector which is based on the Balmorel model (Hindsberger, 2003). For the subsequent analyses we use the results for the year 2005, which is also close to the starting year of the model, i.e. 2000. The objective function of the model is to minimize the system costs for power and heat generation while meeting exogenously set power and heat demand. Besides different technologies (and fuels) the model also allows for different load uses. Thus, the values for benchmarks and production levels for the different technologies are interpreted as the outcomes under optimal decision-making within the given technological and economic framework. Model results may diverge from outcomes observed in reality for several reasons including, among others, differences in dispatching and investment decisions and criteria, market power exerted by power companies or deviations in the underlying model data on technologies or on economic variables.

For the optimal solution, the effects of the following benchmarking regimes are analysed:

a) *One benchmark*: uniform average benchmark for all installations;

b) *Two benchmarks*: uniform average benchmark for lignite- and hard coal-fired installations; average individual benchmark for gas-fired installations;

c) *Three benchmarks*: average individual benchmarks for lignite-, hard coal- and gas fired installations.

Average benchmarks are calculated as the ratio of the sum of emissions and the sum of output levels in the optimum. For example, to calculate the uniform average coal benchmark in regime b), the total emissions from hard coal-fired and lignite-fired plants were divided by total electricity generation from hard coal-fired plants and lignite-fired plants. The number of allowances allocated to a particular type of installation is calculated as the product of the benchmark and the installation’s output level in the optimal solutions. For regimes a) to c) we calculate the distribution in terms of capacity and production. We also analyse the effects of capping the surplus and shortage of EUAs for all regimes compared to historical emissions (double cap). Likewise, we consider the case where only the shortage is capped (single cap).[3] Formally, we use the following allocation function for the double cap

$$(1) \qquad AF = \begin{cases} EV * (1+x) & EV < \dfrac{BM}{(1+x)} \\ BM & \text{if} \quad \dfrac{BM}{(1+x)} \le EV \le \dfrac{BM}{(1-x)} \\ EV * (1-x) & \dfrac{BM}{(1-x)} < EV \end{cases}$$

where AF represents the allocation function [kg/MWh], EV denotes the emission value [kg/MWh], BM stands for benchmark value [kg/MWh] and the cut-off factor x determines the over- and under-allocation in per cent. For example, assume that the surplus and shortage of allowances are both limited to 20 %, i.e. x = 20 %[4]. If the benchmark value exceeds the specific emissions of an installation by more than 20 %, then the allocation to that installation is based on 1.2*EV. Thus, the allowance surplus cannot be higher than 20 %. Likewise, if specific emissions exceed the benchmark by more than 20 %, allocation will be based on 0.8*EV. Thus, the allowance shortage is 20 % at most. The allocation function for x = 20 is displayed in Figure 1 together with the allocation function for x = 0, i.e. when AF=EV. The straight line corresponds to a situation where allocation is based on historical emissions. Clearly, the lower the value of x, the closer the outcome of the allocation will be to conventional grandfathering. The higher the value of x, the closer the outcome of the allocation will be to a pure benchmark allocation. Capping the surplus and shortage of allowances would limit the distributional effects of benchmarking. However, if an installation’s EV is updated to determine allocation in a subsequent phase, capping would then result in additional efficiency losses compared to pure benchmarking. For example, for very efficient installations, additional efficiency improvements are not fully recognized when surplus allocation is limited.

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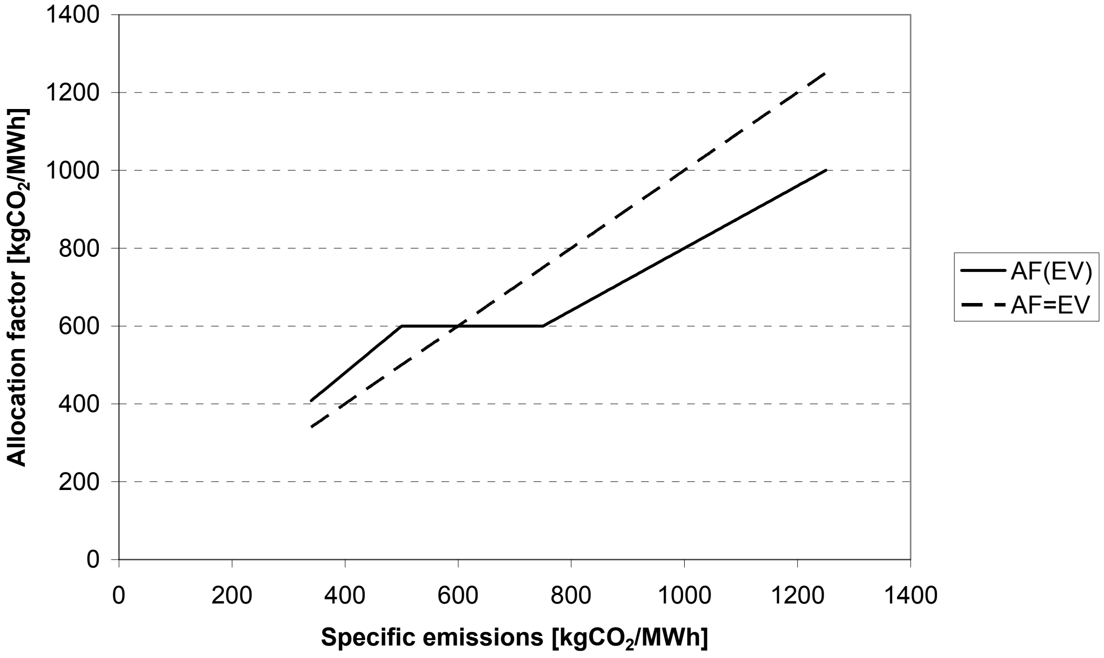
[3] In fact, the regime where only the shortage is capped may also be interpreted as the optimal outcome of the following choice alternatives: (i) allocation based on fixed benchmark, or (ii) allocation based on historical emissions multiplied by (1-percentage cap). For (ii) the model would calculate "historical2" emissions as the product of the benchmark and the production levels in the optimal solution. We would like to thank Thomas Langrock for pointing this out.

[4] For simplicity we assume that historical, current and future production activity levels remain constant. Thus, if allocation is based on historical production levels and if individual emission values also remain constant, the allocation factor determines the surplus or shortage of allowances.

If surplus allocation were limited to 20 %, the benefits of additional specific emission reductions in terms of excess allowances would only be 20 %. Likewise, for installations with a high EV cap, the shortage would limit incentives for efficiency improvements.

Figure 1: Allocation factor (AF) as a function of specific emissions (EV) with allowance surplus and shortage capped at 20 %



Rather than capping the shortage *and* the surplus of allowances, only the shortage *or* the surplus may be limited. For example, if only the shortage is capped, installations receive a benchmark allocation unless this results in a shortage of at least 20 %. Compared to a double cap, such an allocation rule benefits installations which are significantly better than the benchmark, since excess allocation is not limited to a certain percentage share.

4 Results

We first present the results for the cost-efficient generation of power and then for the alternative benchmarking regimes.

4.1 Optimal generation mix

The principal results of the model calculations that made up the first step of the analysis are shown in Table 1. All benchmark values are calculated as average values weighted by the generation of the power plant classes in the model representing the power plants of the electricity system. It should be noted that all the data given in Table 1 represent the generation, capacity and emissions of power plants that generate electricity. Power plants which produce combined heat and power (CHP) are part of the installation mix in the model (CHP makes up a share of 20 % of the total fossil fuel based generation). They are not included to calculate the benchmark, though, because splitting energy input and emissions between electricity and heat generation is arbitrary and because CHP-installations in Germany continue to be subject to special allocation rules in the second phase. The resulting uniform average benchmark value may then be interpreted as the average emission value of fossil fuel-fired non-CHP power plants covered by the EU ETS in Germany. This value is higher than the average specific emissions for the entire electricity grid because our benchmark calculation neither includes CO_2-free sources such as nuclear energy and renewable energies, nor CHP plants, many of which are fuelled by gas. In terms of capacity shares, Table 1 suggests that, in the optimal solution, coal-fired plants account for 55 % of total capacity, lignite-fired plants for 37 % and gas-fired plants for 8 %. In terms of emissions, coal-fired and lignite-fired plants are responsible for about 49.5 % each, while gas-fired plants account for 1 % only.

Table 1: Principal results of the model for different benchmarking regimes

Fuel	Production in 2005 in TWh	Capacity in 2005 in MW	Total CO_2-emissions in Mt	Uniform average benchmark in gCO_2/kWh Regime (a)	Uniform benchmark for coal and lignite, individual for gas in gCO_2/kWh Regime (b)	Individual benchmarks for coal, lignite and gas in gCO_2/kWh Regime (c)
Coal	141.3	24,059	129.0	965	979	913
Lignite	122.1	16,164	129.0			1,055
Gas	6.5	3,732	2.8		433	433

4.2 Distribution of allocation for benchmarking regimes

Results for regimes a) to c) are displayed and summarized in Figure 2, Figure 3 and Figure 4 together with Table 2 and Table 3.

For example, Table 2 indicates that, under the uniform benchmark of regime a), 19 % (22 %) of total installed capacity receive a surplus (shortage) allocation compared to conventional grandfathering, i.e. 41 % of the capacities lie in an interval around 5 % of the benchmark. Notably, 54 % of the installed capacities would receive an allocation corresponding to a surplus or shortage of allowances of more than 10 %. For regime b) this share equals 52 % but for regime c) it is only 23 %). Thus, allocation regimes with a uniform benchmark as in a) or two benchmarks as in b) imply quite substantial distributional effects. Under these regimes, however, the share of capacities which receive a surplus of more than 15 % would be small, i.e. 2 % and 0 %, respectively, compared to 10 % under a uniform benchmark.

As expected, more differentiated benchmarks generally imply smaller distributional effects. Somewhat surprisingly, there is a lower percentage of installed capacity within the 5 % and 10 % intervals for regime b) than for regime a) even though the benchmarks are more differentiated in b). This happens because, compared to the uniform coal benchmark in regime b), the uniform benchmark in a) is closer to the emission value of most hard coal installations which constitute the dominant technology in the base solution with a production or capacity share of well over 50 %. In addition, since many of those coal-fired plants in Germany were built around the same time (early 1970s), their specific emission values do not vary much.

Figure 2: Distribution of capacity in the optimum and for a uniform benchmark regime a)

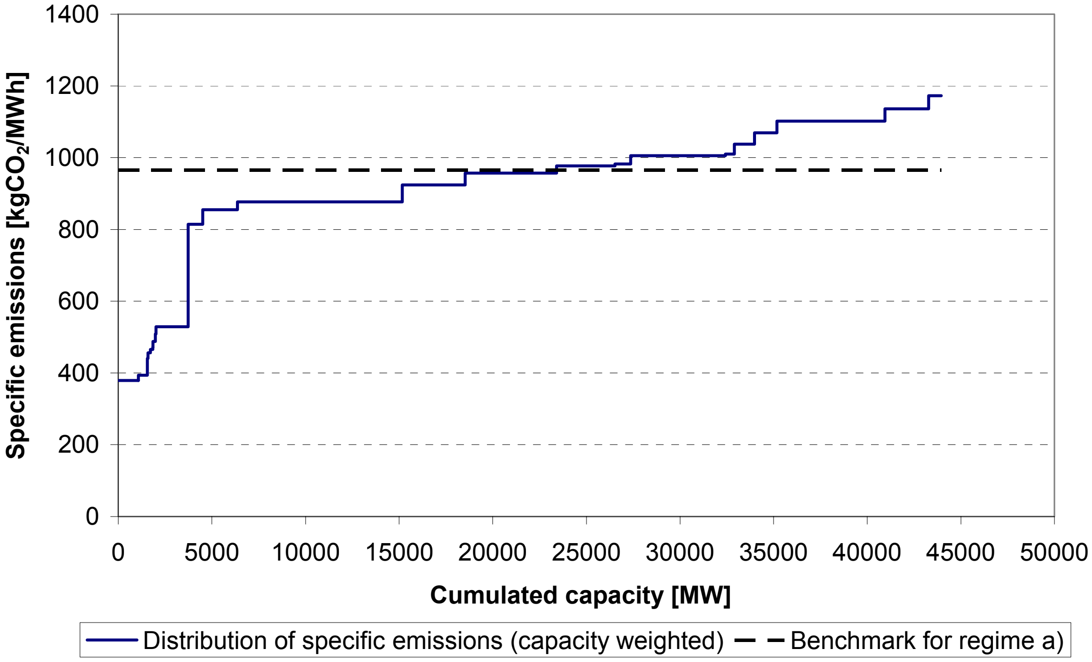


Figure 3: Distribution of generation capacities in the optimum and for a two benchmark regime b)

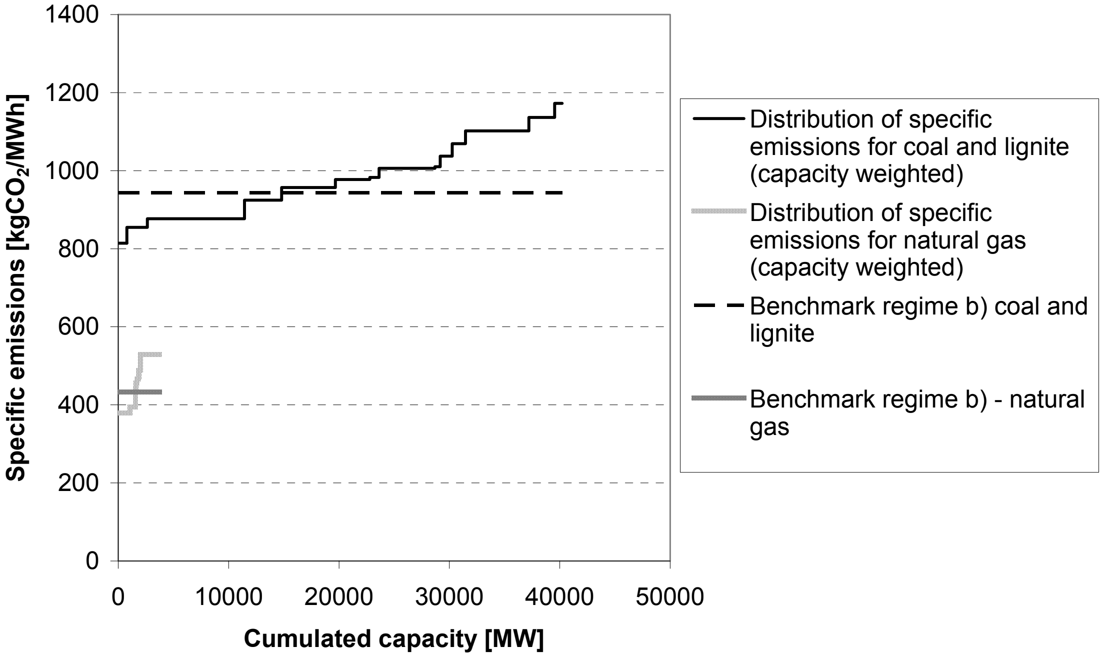


Figure 4: Distribution of generation capacities in the optimum and for a three benchmark regime c)

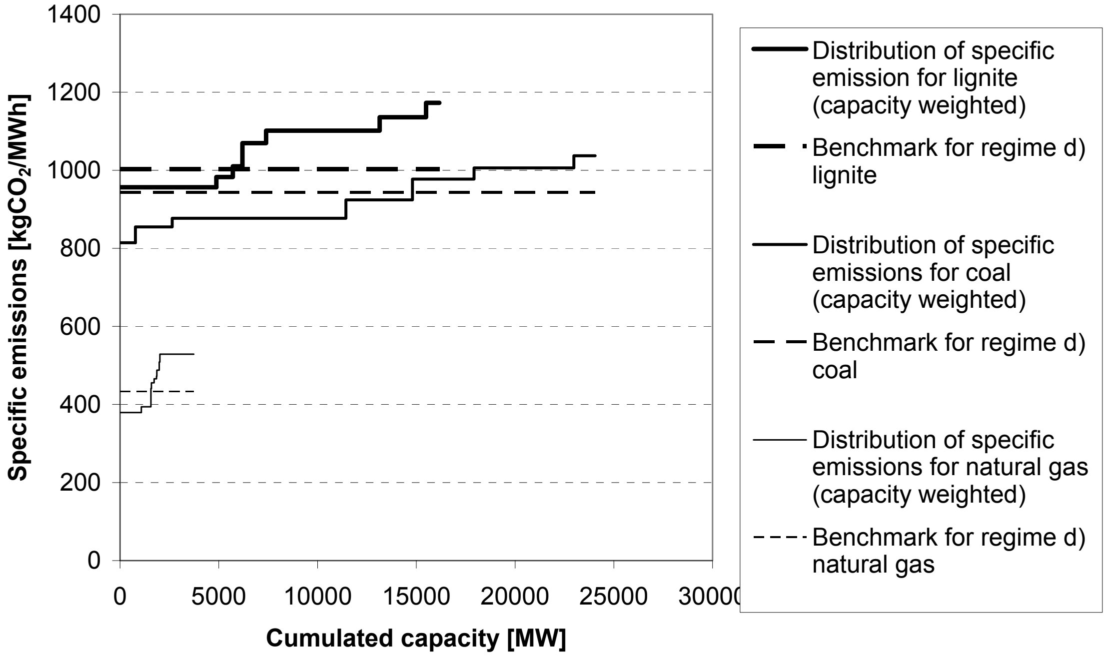


Table 2: Distribution of generation capacities for regimes a), b) and c) with a surplus or shortage of allowances compared to historic emissions (as percentage of total installed capacity)

	Percentage of surplus of allowances*					Percentage of shortage of allowances				
	>20%	20%>=x>15%	15%>=x>10%	10%>=x>5%	5%>=x>=0%	0%>x>=-5	-5%<x>=-10%	-10%>x>=-15%	-15%>x>=-20%	<-20%
Regime a) uniform benchmark										
Gas	8%									
Coal		2%	24%		8%	19%	2%			
Lignite					11%	3%	3%	13%	7%	
Total	8%	2%	24%		19%	22%	5%	13%	7%	
Regime b) two benchmarks, one applied for solid fuels, the other for natural gas										
Gas			2%	1%		0.4%	0.3%	0.4%	4%	
Coal	2%		24%	8%	7%	11%	2%			
Lignite					11%	3%	3%	18%	2%	
Total	2%		26%	9%	18%	14%	5%	18%	6%	
Regime c) three fuel specific benchmarks										
Gas			2%	1%		0.4%	0.3%	0.4%	4%	
Coal			2%	4%	20%	8%	19%	2%		
Lignite			11%	2%	1%	16%	5%	2%		
Total			15%	7%	21%	24%	24%	4%	4%	
Deviations from 100% total are a result of rounding errors.										

Focusing on the surplus and shortage of allowances (compared to conventional grandfathering) for particular fuels in Table 2 suggests that a uniform benchmark leads to a surplus for all gas-fired plants (of more than 20 %). Likewise, nearly half the coal-fired plants would enjoy a surplus allocation of at least 10 %. Thus, the results illustrate how a uniform average benchmark would strongly favour less carbon-intensive power generation processes. Compared to conventional grandfathering these technologies would benefit most from a uniform benchmark, while about 70 % of the lignite-fired plants and almost 40 % of the coal-fired plants would be worse off. By comparison, regimes with differentiated benchmarks imply a shortage of 15 % to 20 % for half the installed gas-fired capacity. For coal-fired plants, regimes a) and b) lead to similar results in terms of the surplus and shortage of allowances, with more than half the installed capacity ending up with a surplus. The reason is that the benchmark for lignite- and coal-fired plants differs from the uniform benchmark only by the impact of the gas-fired plants, which account for only 2.4 % of the total production in the optimal solution.

In regime c), coal-fired capacities with a surplus and a shortage are distributed quite symmetrically. For lignite-fired plants, regimes a) and b) also lead to similar results, but in contrast to coal-fired plants, more than 70 % of the installed capacity of lignite-fired plants exhibits a shortage, which exceeds 10 % for more than half of them. For a regime with three fuel-specific benchmarks, almost 2/3 of the lignite-fired plants (measured in terms of capacity) receive a shortage of allowances rather than a surplus, but only about 5.5 % exhibit a shortage of more than 10 % compared to about 55 % under a regime with a single coal benchmark.

Next, we analyse in more detail the differences in allowances within different fuel categories for regime c). As can be seen from Table 2, distributional effects (in percentage terms within fuel categories) are particularly large for gas-fuelled installations even for regime c) since this category includes gas turbines, which are typically used for peak load only, as well as combined-gas-cycle (CCGT) plants, which may be part of the shoulder or even base load. As a consequence, even for a gas-specific benchmark, almost 80 % of the capacity of gas-fired plants receives either a shortage or a surplus of more than 10 %. For comparison, under a system with three fuel-specific benchmarks, more than 90 % of the hard coal-fired plants receive a shortage or a surplus of less than 10 %. For this regime, Table 3 also shows that only about 4 % of the lignite-fired plants exhibit a shortage of more than 10 % compared to about 55 % under the regime with a single coal benchmark. While 50 % of the gas-fired plants would face an allowance deficit of at least 10 %, the total share would be rather small (4 %). In contrast, 15 % of total capacity (in particular modern lignite plants) benefit from an allowance surplus of more than 10 %.

Table 3: Distribution of the generation capacities for regime c) with a surplus or shortage of allowances compared to historic emissions (as percentage of installed capacity per fuel)

	Percentage of surplus of allowances					Percentage of shortage of allowances				
	>20%	20%>=x>15%	15%>=x>10%	10%>=x>5%	5%>=x>=0%	0%>x>=-5	-5%<x>=-10%	-10%>x>=- 15%	-15%>x>=- 20%	<-20%
Gas	0%	0%	29%	13%	0%	4%	4%	4%	46%	0%
Coal	0%	0%	3%	8%	37%	14%	34%	4%	0%	0%
Lignite	0%	0%	30%	5%	3%	43%	14%	4%	0%	0%
Total	0%	0%	15%	7%	21%	24%	24%	4%	4%	0%

4.3 Distribution of allocation for benchmarking regimes when both surplus and shortage are capped

The above results imply that differentiated benchmarks have lower distributional effects but that these may still be substantial. These distributional effects can be limited by capping the shortage and/or the surplus of allowances. If the rate for the maximum surplus and shortage of allowances is set at the levels of 5 %, 10 %, 15 % or 20 %, the results already displayed in Table 2 and Table 3 can be used to analyse the distributional implications for benchmarking regimes a), b) and c). For example, to analyse the effects of capping the surplus of allowances at 10 % (compared to historical emissions), in Table 2 the values of the three cells in a row representing a surplus of more than 10 % have to be added to the values of the neighbouring cell to the right in each row. Similarly, to explore the effects of capping the shortage of allowances at 10 %, the values of the three cells in a row representing a shortage of more than 10 % have to be added to the values of the neighbouring cells to the left in each row. For a double cap, both types of calculation have to be carried out. Depending on the objective of the allocation, a wide range of outcomes can be generated by various combinations of benchmarking regimes, capping the shortage and/or the surplus of allowances, and cut-off factors. In general there is a trade-off between the various objectives. Results show that the distributional effects of benchmarking can be significantly constrained by a double-cap or by a single-cap approach. On the one hand, capping the surplus may also limit recognition of early action. Likewise, as also explained above, capping the shortage will lead to lower incentives for new investments. For distributional reasons and because of stranded investments, fuel-specific benchmarks may be the most likely allocation regime for existing installations because they are politically more palatable. If, for example, the shortage of allowances was limited to 10 %, the results in Table 2 suggest that 8 % of the installations (in terms of capacity in the base solution) would benefit from a capped allocation compared to a simple fuel-specific benchmark under regime c). Since 46 % of the capacity of gas-fired installations would receive the capped allocation, gas turbines would benefit the most in terms of percentage shares. By contrast, since the emission values of 96 % of the hard coal plants are below 110 % of the benchmark for hard coal, a single cap of 10 % for the allocation shortage would hardly be effective for this technology. From Table 2 it is also clear that if early action is to be rewarded, a cap of 10 % (and lower) on the surplus would start to be binding, in particular for lignite-fired power plants. Conversely, if the intention is to create effective incentives for new investments in old lignite-fired and old hard coal-fired power plants for a large share of installations, the cap on the shortage should be set to at least 10 %. Compared to a 5 % cap, a cap of 10 % on the shortage would provide incentives to invest in an additional 14 % of lignite capacities and 34 % of hard coal capacities (18 % of total installed capacity).

4.4 Effects of benchmarking regimes on the total number of allowances allocated to the power sector

In general, limiting the surplus and shortage of allowances could change the total number of allowances compared with the size of the allocation budget under conventional grandfathering. If the total number of allowances available for all installations (ETS budget) is fixed – as is usually the case in EU 15 Member States – the allocation to installations outside the electricity sector would also change, unless appropriate adjustment factors were introduced to guarantee that the budgets to the power installations are identical for all allocation regimes. Since the electricity sector tends to account for a large share of the ETS budget in most Member States, these changes may be relatively large. In general, the effects on the budget for power installations depend on the distribution of installations in terms of emission values and on the cut-off factors. For example, a benchmarking rule with a double-sided cap on both the surplus and shortage of allowances may result in a lower budget than conventional grandfathering if the share of very inefficient installations is relatively high and the cap is high.[5] Likewise, a benchmarking allocation

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[5] Note that a percentage cap implies that a shortage and a surplus of the same percentage are associated with very different quantities. For identical production levels, the shortage is much higher than the surplus.

where only the shortage is limited may require a higher budget than conventional grandfathering if the shortage is high and a large share of overall production is generated with highly efficient installations. The results in Table 4 suggest that the total allowance budget for a benchmarking rule with a double-sided cap would in general not differ significantly from the budget under conventional grandfathering. Only for a uniform average benchmark in regime a) would a cap of 15 % or more result in a substantial deficit.[6] Since, in Germany, the allowances allocated to the electricity sector account for almost 2/3 of the ETS-budget, a deviation of 1 % would translate into allowances for about 5 Mt of CO_2 and noticeably change the allowance budgets available to other installations. A benchmarking regime where only the shortage (but not the surplus) were capped would translate into a substantially higher allowance budget for the power sector compared to conventional grandfathering only in regimes a) and b) when the cut-off factor is low (see Table 5). In these cases, the difference for inefficient lignite-fired plants is rather low, while the surplus is quite large, in particular for gas-fired and coal-fired plants.

Table 4: Effects of allocation regime on total allocation for symmetric cut-off factors on the surplus and shortage of allowances (compared to historic emissions)

	Cut-off factor for surplus and shortage			
Cut-off factor for surplus and shortage	5%	10%	15%	20%
Regime a) uniform benchmark	-0.3%	-0.5%	-1.2%	-1.1%
Regime b) two benchmarks natural gas and solid fuels	0.1%	0.0%	0.0%	0.0%
Regime c) three benchmarks: natural gas, hard coal and lignite	-0.2%	-0.1%	0.0%	0.0%

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[6] At first glance it may seem surprising that, for regime a), the difference to the budget share under conventional grandfathering is lower for a cut-off rate of 20 % than 15 %. The reason is that for a cut-off rate of 15 %, two types of lignite-fired power plants in the model are subject to the cap (on the shortage side) and one type of hard coal-fired plant and all gas-fired plants are subject to the cap (on the surplus side). When the cut-off rate is increased to 20 %, on the one hand, the two types of lignite-fired power plants move just inside the cap and receive a benchmarking allocation. For these plants the shortage in terms of allowances is now 15.04 % and 17.69 % (compared to 15 %). On the other hand, the surplus of all gas-fired and of the one type of coal-fired power plants increases from 15 % to 20 %. The net effect is an increase in the budget of 0.1 %.

Table 5: Effects of allocation regime on total allocation for cut-off factors on the shortage of allowances (compared to historic emissions)

	Cut-off factor for shortage			
Cut-off factor for shortage	5%	10%	15%	20%
Case a) uniform benchmark	2.6%	1.0%	0.1%	0.0%
Case b) two benchmarks natural gas and solid fuels	2.3%	0.7%	0.0%	0.0%
Case c) three benchmarks: natural gas, hard coal and lignite	0.8%	0.0%	0.0%	0.0%

5 Conclusions

Using benchmarks rather than historical emissions as the basis to allocate emission allowances to existing installations covered by the EU ETS may have several advantages. In particular, benchmarks inherently recognize early action, may allow for simplified rules for closures (and possibly new projects), result in fewer distortions in the case of updating, and can also facilitate harmonized allocation rules across the EU. Also, benchmarking can provide higher incentives for replacing old installations unless the allocation for the old installation is kept or transferred. However, benchmarks for existing installations may also be associated with substantial distributional effects (sunk costs) and require sufficiently homogenous products, such as electricity. Using a regular power market model for the German electricity sector, we find that the distributional effects associated with a single uniform benchmark are rather high, which may render this particular allocation method politically infeasible. Benchmarks differentiated by fuels would lower the distributional impacts substantially. However, since the share of gas-fired plants in total capacity is rather small in Germany, the differences between an allocation regime with a uniform benchmark and a regime with benchmarks for hard coal-fired and lignite-fired plants on the one hand and gas-fired plants on the other tend to be rather small. By contrast, when applying three fuel-specific benchmarks, our results suggest that only eight per cent of the total capacity would suffer from a shortage of allowances of more than 10 %. Thus, with the possible exception of gas-fired plants, our results provide little support at the aggregate level for additional sub-groups based on loads, size, technologies, etc. Compared to a regime with a single coal benchmark, where 70 % of the installed lignite power capacity would face an allowance shortage of at least 10 %, this share would only be 4 % under a regime with three fuel-specific benchmarks. This result rationalizes the observed lobbying of operators of old-lignite fired plants in Germany against a single coal benchmark.

Limiting the surplus and shortage of allowances may further moderate the distributional effects of benchmarking relative to conventional grandfathering. As a drawback, the benefits from the reduced emission values would also be capped if the allocation regime prevailed for future periods, resulting in weakened incentives for improvements in energy efficiency. In addition, capping the surplus would also limit the extent to which early action is credited. Our result for the allocation regime with three fuel-specific benchmarks imply that the cut-off factor for the surplus should be at least 10 % if a substantial share of the lignite-fired power plants are to be rewarded for early action. Likewise, if benchmarking were to provide incentives to replace a large share of old lignite-fired power plants, the cut-off factor for the shortage should be set at 10 % or higher. Finally, our results for most of the allocation regimes with and without symmetrical cut-off factors for the surplus and shortage of allowances (compared to historical emissions) suggest that the benchmarking regimes analysed would require about the same size allowance budget for the power sector as conventional benchmarking. However, if only the shortage of allowances were limited, low cut-off factors would lead to substantially lower allocation to the non-power installations under a fixed overall allowance budget.

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Appendix A: Incentives to invest under benchmarking and conventional grandfathering in the EU ETS

Proposition 1: If allocation is terminated after a closure, and allowances may not be transferred to a new installation a benchmarking allocation for existing installations provides higher incentives to invest in new replacement installations compared to conventional grandfathering.

Proof: For simplicity, we assume that existing installations would continue to produce the same output and emissions as in the past. Likewise, we normalize production to unity. We also assume that both methods result in a short position for existing installations. When comparing the effects of benchmarking and conventional grandfathering we assume that everything else (e.g. allocation to new installations) is equal. Under these assumptions we may restrict the analysis to comparing the economic value of the avoided allowance purchase. The benefits of investing in a new project under conventional grandfathering at the beginning of a trading period are then

$$\pi_G = (EV - \gamma EV)\tau p \qquad (A1)$$

where EV stands for specific emissions, which also correspond to total emissions because production levels are normalized, γ is the adjustment factor, τ reflects the length of the trading period, and p is the allowance price. Analogously, the benefits of investing in a new project at the beginning of a trading period when existing installations receive a benchmarking allocation may be expressed as

$$\pi_{BM} = (EV - \gamma BM)\tau p \qquad (A2)$$

where BM stands for the benchmark specific emissions level. Subtracting (A1) from (A2) yields the additional benefits of benchmarking compared to conventional grandfathering

$$(EV - BM)\gamma\tau p \qquad (A3)$$

Since installation rules for existing installations are assumed to result in a short position, the difference is positive, which completes the proof for Proposition 1.

As a *corollary*, it follows that the additional incentive to invest under a benchmarking allocation is increasing in the adjustment factor, in the length of the trading period, in the price for EU allowances and in the difference between the old installation's specific emissions and the benchmark.

Proposition 2: If allowances may be transferred from existing to new replacement installations, allocations for existing installations based on benchmarking and conventional grandfathering provide identical incentives to replace old by new installations.

Proof: Incentives to replace an old installation, which result from the participation in the EU ETS may stem from two factors. First, operators avoid expenditures for purchasing allowances for existing installation. Second, because the new installation is assumed to be more carbon-efficient than the old installation the resulting surplus of allowances may be sold. Thus, incentives to replace the old installation under conventional grandfathering are now

$$\pi_G = (EV - \gamma EV)\tau p + (\gamma EV - EVN)\tau p \qquad (A4)$$

where EVN is the (specific) emission value of the new installation. Output of the new installation is assumed to be the same as for the old installation and normalized to one. Similarly, for allocation based on benchmarks we get

$$\pi_{BM} = (EV - \gamma BM)\tau p + (\gamma BM - EVN)\tau p \qquad (A5)$$

Collecting terms in a (A4) and (A5) yields

$$\pi_{BM} = \pi_{BM} = (EV - EVN)\tau p \qquad (A6)$$

Thus, for both methods the incentives to replace existing installations are independent of the allocation rules for existing installations. Instead, they depend on the difference between the emissions of the new and the old installation.

Appendix B: Short description of the applied electricity market model

The applied electricity market model bases on the open source model BALMOREL (Ravn 2001). The methodological foundations of the model lie in a stepwise multi-period linear optimization for the electricity and heat system. The objective function is to minimize the overall system costs for electricity and heat generation, transmission and distribution. The problems are defined as such that the characteristics of the power and heat market can be formulated as restrictions to the objective function. The exogenously given demand for electricity and the demand for heat of a country or region considered are the driving parameters of the model. The demand is transferred into a load for every time segment of the model with use of an exogenous load distribution function. For the supply of power and heat capacity for each time segment in the amount equivalent to the load, the model relies on a database of existing power and heat generation capacity and the option to make use of new capacity. The techno-economical parameters of the generation technologies are exogenously given in the database (a summary of the fuel specifications is given in Table B-1 and of the technical parameters considered in Table B-2). The model operates with several levels of temporal subdivisions. The overall period analyzed is divided into years. These in turn are subject of a division into seasons and time segments of seasons. The latter are usually interpreted as days. In the applied configuration of the model, a subdivision of years into four seasons has been chosen. For each season, a representative week-day and week-end day with a subdivision of 12 two-hour periods has been used. For simplification, in the version applied for the present analysis a demand function has been chosen where the elasticity of demand is set at zero. The input prices of energy carriers for the model are part of the parameters externally set as boundary conditions and are inelastic with respect to the demand created by the electricity system represented in the model.

The generation of electricity and heat is derived internally in the model. In order to do so, generation cost functions are found for each time period. This is done based on the exogenous data on the generation technologies, on the fuel prices and the other boundary conditions emissions taxes and fuel taxes. New investments can be realized internally at the beginning of a year for electricity generating capacity and for heat generating capacity.

Table B-1: Power generation capacity by primary energy in the model database, Germany, 2000

	Capacity in GW	**Percent of total installed capacity**	**Difference to Data of VIK (2002) in GW**
Nuclear	21.3	18%	-2.3
Lignite	19.5	17%	-2.4
Hard coal	37.5	32%	5.2
Fuel oil	5.9	5%	-1.7
Nat Gas	18	15%	-4.4
Hydro	8.9	8%	-0.2
Other	6.3	5%	2
Total	**117.3**	**100%**	**-3.6**

Table B-2: Parameters for the representation of energy conversion technologies in the Balmorel model

Parameter	**Criteria/Values/ units**
Type of Technology	
Fuel used by technology	type of fuel
Cb-value of CHP units	
Cv-value of CHP units	
Fuel efficiency	%
Investment costs	MEuro/MW
Variable operation and maintenance costs	Euro/MWh
Fixed operation and maintenance costs	kEuro/MW
First year of availability of technology	year
Technology available for new investments	Binary: 0/1

Table B-3: Principal input data and results of the optimisation model for the analysed plants

Main fuel	Efficiency		Specific emissions in 2005 (gCO2/kWh)	
	Max.	Min.	Min.	Max
Natural Gas	0.54	0.39	379	529
Hard Coal	0.42	0.33	814	1037
Lignite	0.38	0.31	957	1173

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