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## On multi-period emissions trading in the electricity sector

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# **HWWA Discussion Paper**

## **On multi-period emissions trading in the electricity sector**

**Sven Bode**

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## **On multi-period emissions trading in the electricity sector**

### **ABSTRACT**

Emissions trading schemes on entity level are becoming more and more important in the context of controlling greenhouse gases. The directive on a Europe-wide trading scheme is a prime example. Prior to the start of such a scheme, a number of design features have to be agreed upon. Regarding the allocation of allowances, a distribution that is (almost) free of charge has been the method of choice. An aspect that has interestingly attracted little attention thus far is the question of how to allocate emission rights over time, i.e. in single, subsequent periods that exist in real trading schemes. In this paper, different allocation options are applied to the electricity sector. A power market that mirrors reality with five different types of power plants (hydro, nuclear, lignite, coal and gas) is simulated over two periods. On the demand side, three different load curves are assumed (winter, summer, transition). For each demand curve different elasticities are analysed. Supply and demand are matched on an hourly basis. The allocation is either based on absolute emissions or on a generation benchmark. The base period / generation metric is either constant or updated over time. Thus, four different allocation options exist. It turns out that the electricity sector as a whole gains from the introduction of the instrument. Its aggregated gross margin is considerably higher with an allocation based on a constant period / generation metric. It is thus the preferred allocation option. This result contradicts other recent studies that assumed completely inelastic demand. Single plant operators may, however, win or lose in terms of the net financial impact. On the installation level, preferences regarding the different allocation scheme are a function of the fuel used.

**Key words:** allocation of GHG allowances, electricity sector, multi-period emissions trading

**JEL- Classification:** H 20, L 94, M 11, Q 25, Q 28

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## Introduction

In the context of environmental regulation, emissions trading has garnered more and more support in recent years (Stavins 2003). On installation level, the most important example system is the European emissions trading scheme (EU-ETS) that started in 2005. In this scheme, certain installations, i.e. major immobile sources of GHGs are obliged to participate in a cap and trade scheme. The allocation of allowances, i.e. of emission entitlements<sup>1</sup>, is perceived as a very important issue from the companies' point of view and has been part of intensive bargaining so far. Two main approaches have been focussed on during the discussion between governments and participants, namely an allocation based on emissions in a reference year and the use of an emission benchmark. With both options, allowances are distributed free of charge. However the question of how to design the allocation over time, i.e. in subsequent periods, has attracted little attention thus far. The impact of different allocation options on single installations has only rarely been addressed (for example Burtraw et al. 2001 and 2002, Bode 2006). Existing literature, which is briefly reviewed below, generally either concentrates on the sector level or provides an analytical analyses.

Against this background, the present article analyses the impact of different allocation options on installations in the electricity sector, which is the major emitter of carbon dioxide compared to other stationary sources. The focus is on the relative impacts of the allocation on different power plants subject to the scheme. Effects on installations that are not subject to the trading system are not considered.

A simulation of an artificial but realistic electricity market is provided. The analysis is limited to a short-term perspective. On the one hand, this is due to the fact that politically, a short-term perspective is likely to influence current legislation the most. On the other hand, the path for auctioning the allowances is already slightly paved in the European scheme. With a 100 percent auctioning however, the problems discussed below do not exist anymore.<sup>2</sup>

The paper is structured as follows: The following section reviews the impact of emissions trading on firms from a theoretical perspective. Section three discusses different options for

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<sup>1</sup> The term emission right and allowance are used interchangeably.

allocating allowances free of charge and the implications for multi-period emissions trading. A numerical example for the electricity sector is analysed in detail in section four. Section five concludes.

## **Emissions trading and its impact on firms**

Emissions trading is a market based instrument. It allows a cost-efficient meeting of a predefined emission target. In the equilibrium, marginal abatement costs are the same for all participants. They are not obliged to use a certain technology for emission reductions. The only obligation they have to fulfil is to surrender as many emission allowances as the emissions they released into the atmosphere during a given period in time. They are then free to reduce emissions internally or to buy allowances on the market. Whether or not to buy is a question of in-house marginal abatement costs<sup>3</sup> and the allowance price. Whichever is cheaper is chosen.

Implementing emissions trading schemes requires a number of decisions to be taken regarding the design.<sup>4</sup> One aspect is the allocation of the allowances. They may either be provided free of charge or for a fee. Economists have argued in favour of a fee-based allocation or, more precisely, an auction at least for schemes on company level. An allocation free of charge would result in extra revenue for the recipients of the allowances and in reduced efficiency on a macro-economic level (Cramton and Kerr 2002, FIELD 2000 p. 31, Speck 1999, Woerdman 2000 p. 620). Parry (2002, p. 7) argues that there is also a strong case for auctioning on distributional grounds. Bohm (2002) argues that this question can only be answered when comparing the concrete designs of different schemes. Burtraw et al. (2001) compare three different allocation options for the electricity sector in the US. They find that the costs to society are about one-half with auctioning compared to the two free of charge options.<sup>5</sup>

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<sup>2</sup> The price increase and the resulting additional producer rents, which are discussed below, would persist. With a 100 % auctioning, no rule for allocating the allowances (and thus the scarce resource) would be required. The scarcity rent would be collected by the government as in the case of a CO<sub>2</sub> tax.

<sup>3</sup> Abatement costs in this paper are costs due in-house abatement. Compliance costs are the sum of abatement costs and expenses due purchase or sale of allowances on the market.

<sup>4</sup> Examples are: length of the compliance period, units traded, monitoring rules, liability etc. For a more detailed discussion see AGE 2001, AGO 1999, Boemare et al. 2002, CCAP 1999, CCAP 2002, WBCSD 2001, p. 8, UNEP and UNCTAD 2002.

<sup>5</sup> The authors use the revenue from the auction in the least efficient way discussed in literature, namely the direct redistribution to households.

Emitters have so far asked for an allocation free of charge.<sup>6</sup> They argue that the additional financial burden of paying the fees would be too high.<sup>7</sup>

The argument of the additional financial costs is only partly true. Allowances are scarce, at least at the start of the scheme. Thus, there will be a price for allowances although they are allocated for free. Their use for production involves an opportunity cost as they can be sold in the case of non-production. Consequently producers will raise the product prices according to the product's emission intensity and the costs for emitting carbon.

The effect on the market can be studied in comparison to a per unit tax.<sup>8</sup> Assume a competitive market for a certain product. Denote the demand curve for the product by  $D$  and the supply prior to the implementation of the trading scheme by  $S_1$  (see Figure 1). The equilibrium price  $p^*$  and the corresponding quantity  $q^*$  arise from the intersection of the two curves. Assume that a competitive allowance market emerges. All participants face the same  $CO_2$  price that translates into opportunity costs within the firms' cost and pricing strategy. In the case of all producers having the same emission intensity per unit of output, the additional opportunity costs for  $CO_2$  emissions result in an upward shift of the supply curve (see  $S_2$  in Figure 1). This shift in turn results in a new equilibrium with the equilibrium quantity  $q^\#$ . Consumers face the price  $p^\#$ . Producers collect the sum that would have been transferred to government in the case of an introduction of a per unit tax. The magnitude of the additional rent depends on the slope of the supply and demand curve.

In the context of the EU ETS these windfall profits, especially those collected in the electricity sector, have been criticised. To reduce these windfall profits, partial auctioning would be one solution. Goulder (2002) analysed this issue for the US fossil fuel industries. He finds that only about 13 percent of allowances need to be distributed free of charge if a loss of profit for these industries is to be avoided.<sup>9</sup>

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<sup>6</sup> For their position in the context of the EU trading scheme see COM (2001), p. 2.

<sup>7</sup> Under the trading scheme at least 95% of allowances have to be allocated free of charge for the initial period 2005-2008 and at least 90% for the subsequent period (EU 2003). Stavins (2003) reports the same for the relevant non-GHG trading schemes in the US.

<sup>8</sup> For general example see Pashigian (1995, pp. 313-316); for the specific comparison Goulder (2002).

<sup>9</sup> Regarding the EU trading scheme, current legislation already provides the possibility for such a change. See footnote 7.

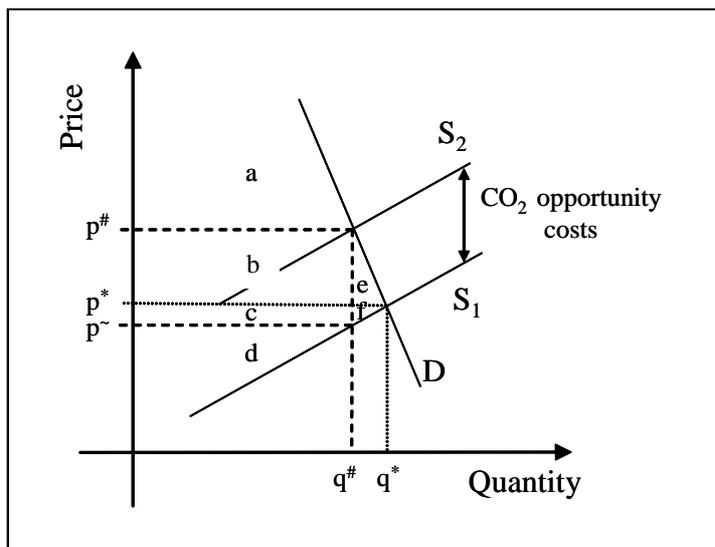


Figure 1: Impact on CO<sub>2</sub> costs on the market equilibrium

With regard to the financial implications from emissions trading for companies there are two aspects. First, the market effect, i.e. the windfall profits, and second compliance costs. The latter accrue from buying or selling allowances on the market. Both aspects will be analysed in more detail below.

### Options for allocating emission allowance free of charge in multi-period emissions trading

The options to allocate allowances free of charge are almost unlimited (AGE 2001, AGO 1999, Boemare et al. 2002, CCAP 1999, CCAP 2002, Holmes et al. 2000, MIES, 2000, Nera 2002, NZME 1998). However, two approaches have attracted special attention<sup>10</sup>:

- an allocation based on emissions in a certain period (what is referred to as emission based allocation below)
- the use of a benchmark, i.e. specific emission factor

With regard to the latter option, one should note that the benchmark has to be multiplied with the reference figure of the benchmark in order to get an absolute emission figure. Formulae are given below. Bode (2003) showed that top-down allocation approaches, i.e. approaches

<sup>10</sup> See for example the existing schemes in the US or the national allocation plans under the EU ETS.

where calculated individual allocations are adjusted by a correction factor in order to match cumulative individual allocations and national allowance budgets<sup>11</sup>, result in an allocation that is proportional to output only (see also Annex 1). This approach is also referred to as generation benchmark below.

With regard to the allocation in a multi-period trading scheme, both abovementioned approaches can be used. However one has to define if the period or the reference figure mentioned is fixed in time or updated. Both ways have advantages and disadvantages. Ahman et al. (2005) refer to this as the “historic” dilemma. They propose a Ten-Year Rule in order to find a compromise.

A number of analyses concerning free of charge allocation schemes exists. The majority (exceptions are mentioned below) however, are of analytical nature or concentrate on the sector or society level. Numerical examples on the plant level are less common, especially with regard to GHG emissions trading schemes. Analyses of multi-period problems are even less common.

Böhringer et al. (2003), for example, analyse an emission and an output based allocation in order to determine the trade-off between a compensation of energy intensive industry for the adverse impacts from regulation and economic efficiency. They conduct a comparative static CGE analysis and find that the trade-off depends strongly on the allowance price on the international market. With regard to the concrete allocation scheme the first and the second best design depends on whether the system studied is open or closed. Rhedanz et al. (2004) analytically analyse different allocation options using multi-player/two-period models. Companies are the same size and have a turnover of unity. Furthermore, they analyse the allowance market only.

Fischer (2001) shows that in general, rebating revenues from environmental regulation based on the firms’ output can provide an incentive to increase output. This may result in sub-optimal abatement behaviour compared to the social optimum. The reasoning behind this argument is that players must consider the opportunity costs of future allocations in today’s cost functions as long as this future allocation is related to today’s emission or production.

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<sup>11</sup> As foreseen by the emission targets of the Kyoto Protocol

There are thus two countervailing effects of different opportunity costs.

- 1) Opportunity costs for using entitlements received for free in the present period, which may increase total costs
- 2) Opportunity costs for allocations in future periods that may results in a reduction of total costs.

This is depicted in Figure 2. Equations are given in the model section below.

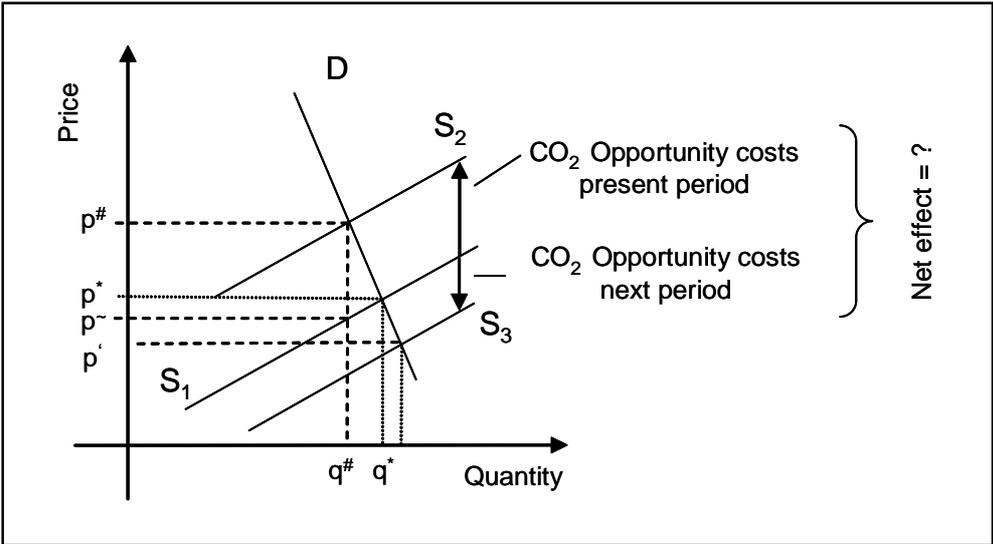


Figure 2: Countervailing effects of different kind of opportunity costs

Other studies focus more on the electricity sector without explicitly referring to efficiency. The Balmorel project (Balmorel 2001) resulted in a detailed model of the electricity and the combined heat and power market in the Baltic Sea region. It provides a long-term analysis of the price for heat and power until 2030. The price increase found is explained by the restructuring of the supply system and increases in fuel prices. Costs for emissions are not mentioned. Emission trading is only assumed for deriving an aggregate abatement cost curve for this region. No different allocation schemes are studied. Hauch (2003) focuses on electricity trade and CO<sub>2</sub> reduction in the northern European power market. The investigation is restricted to country level. Munksgaard et al. (2002) analyse the impact of internalising external costs in the northern European power market using the same model as the previous author. They show how cross-border trade and prices are affected in different scenarios such as under a coordinated and a national approach. In order to regulate the power sector a tax is applied and the authors point out that the model is appropriate for long-term analyses. UBS (2003) provides an analysis of the German electricity market until 2010. Apart from three

different allocation schemes they also consider other issues such as the phasing out of nuclear energy and the aging of plants etc., so that a clear understanding of the impact of the allocation is not possible.

As mentioned above, Burtraw et al. (2001) study the electricity market in the US in terms of both its efficiency and equity. In a paper that follows (Burtraw et al. 2002), the authors introduce “the auction paradox” according to which generators as whole would be better off under an auction than with a generation performance standard<sup>12</sup>, as electricity prices are higher in the case of the former. The concrete distributional effects depend on the fuel use in the power plant analysed and on whether or not a plant is entering the market. They compare two different allocation options free of charge<sup>13</sup>, namely grandfathering and a generation performance standard. While both consider generation as the metric for allocating the allowances, they differ in the reference period. The former uses a constant base year (and is thus equivalent to the “generation benchmark constant” in this paper) whereas the latter uses an updated one (which is equal to the “generation benchmark updating”)<sup>14</sup>. However, they do not consider any emissions based allocation as is being discussed in Europe. From the European discussion it also seems somewhat strange that they allocate allowances to non-hydro renewable installations – at least for the performance standard approach.<sup>15</sup> Sijm et al. (2005) study CO<sub>2</sub> price dynamics for the electricity sector under the EU trading scheme but do not focus on different allocation schemes. Bode (2006) focuses on the effects different allocations options have on the power generators in multi-period schemes. In order to avoid the consideration of the opportunity costs in future periods, he assumes a completely inelastic demand curve. Although this was meant well, it is not correct. On the contrary, the more inelastic the demand the greater the price effect on the power market (see Figure 2).

Against this background, the impact of different allocation rules in multi-period emissions trading for power generators is analysed in the next section.

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<sup>12</sup> The generation performance standard corresponds to the output-based allocation used in this paper.

<sup>13</sup> Additionally, a revenue raising auction is analysed.

<sup>14</sup> At least it seems to be equivalent. They author only state that according to grandfathering allowances are allocated “...on the basis of a historic measure such as emissions or generation.” (Burtraw et al. 2002, p. 52) The context, however, suggest that generation is chosen.

<sup>15</sup> It remains unclear whether allowances are allocated to non-hydro renewable installation under the grandfathering approach, too. In a sensitivity analysis allowances are even allocated to hydro and nuclear installations.

## **Multi-period emissions trading in the electricity sector**

Among all stationary sources, the electricity sector has a major share of CO<sub>2</sub> emissions (UNFCCC 2005). The sector is thus (technically) easy to regulate and to monitor. Power plants are indeed subject to different trading schemes.<sup>16</sup>

The power market has special characteristics compared to other products that must be considered during any analysis in this field. These are briefly described below.

### ***Some explanatory remarks - supply and demand side characteristics***

Electricity is a homogenous product for which different production options exist. These differ considerably with respect to specific GHG emissions. Lignite fired power plants incur the highest specific emissions. Other plants such as nuclear or renewable do not produce CO<sub>2</sub> emissions during production. The efficiency of the plant is also important with regard to the resulting emissions. Storage of electricity is possible, though much more complicated and expensive when compared to other goods.

As mentioned, the paper focuses on the short-term implications. The short-term electricity market is driven by short-term marginal costs (UBS 2003, p. 29). The most important parts of these are fuel costs and operation and maintenance (Balmorel, 2001, p. 20).

The different types of plant also differ with regard to technical aspects as for example operational flexibility. Consequently, they are differently suited to the provision of peak power. Demand varies throughout the day. Demand is generally low during the night when most people sleep and peaks at around noon. Demand also changes over the year.<sup>17</sup>

When supply and demand match in functioning markets, system economics will determine that the lowest marginal cost plant will be operated first (UBS 2003, p. 32). A merit order curve develops. With changing demand the equilibrium price also changes during the day.

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<sup>16</sup> For example in the US Acid Rain and RECLAIM programmes or the EU-ETS

## The impact of CO<sub>2</sub> costs

CO<sub>2</sub> emissions imply external costs<sup>18</sup>. They are currently, however, rarely included in the production costs due to lack of appropriate regulation. In case it is done, production costs rise depending on the emission intensity and the costs, which in the case of emissions trading equals the allowance prices. With different additional costs, the merit order curve may change. For example, a plant with low operational costs and high specific CO<sub>2</sub> emissions that is competitive in the absence of carbon costs may become uncompetitive if costs for CO<sub>2</sub> emissions must be added to the operational costs. Consequently, the equilibrium price may also change.<sup>19</sup>

## The Model

An artificial but close to reality power market is simulated in order to analyse the implication of different allocation options. It is important to note that effects outside the power sector are not considered.

## The market

Two periods are studied and a perfectly competitive market is assumed. The supply side consists of  $i = 1, 2, \dots, N$  installations which use either water, uranium, lignite, coal or natural gas as fuel.

With an allocation based on a constant reference figure, the individual short-term supply curve of installation  $i$  in hour  $t$  in period  $r$  is as follows<sup>20</sup>:

$$S_{t,r}^i = (c_r^i + k_r^i)q_{t,r}^i \quad \text{if } (c_r^i + k_r^i) \leq p_{t,r} \quad (1a)$$

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<sup>17</sup> Load curves for various European countries can be found in UCTE (2002)

<sup>18</sup> See for example COM (2003).

<sup>19</sup> It should be noted that the objective of emissions trading is to meet the overall emissions target cost-efficiently and not to drive emission intensive plants per-se out of the market as stated by UBS (2003). If total costs, i.e. production and emission costs are competitive, emission intensive plants may stay in the market.

<sup>20</sup> Remember that a short-term market is studied and that thus only short-run marginal costs are considered.

$$S_{i,t} = 0 \quad \text{if } (c_r^i + k_r^i) > p_{t,r} \quad (1b)$$

$$\text{s.t. } q_{t,r}^i \leq q_{\max}^i \quad (2)$$

$$\text{with } k_r^i = e^i p_r^{CO_2}$$

Where  $S_{i,t}^i$  = supply of installation  $i$  in hour  $t$  in period  $r$  (MWh),  $c_r^i$  = short term marginal costs of installation  $i$  in period  $r$  (Euro/MWh),  $k_r^i$  = specific CO<sub>2</sub> costs for installation  $i$  in period  $r$  (Euro/MWh),  $q_{t,r}^i$  = power of installation  $i$  in hour  $t$  in period  $r$  (MW),  $p_{t,r}$  = electricity price in hour  $t$  and period  $r$  (Euro/MWh),  $e^i$  = emission intensity of installation  $i$  (t CO<sub>2</sub>/MWh),  $p_r^{CO_2}$  = costs of CO<sub>2</sub> allowances in period  $r$ , which is equal to the market price (Euro/t CO<sub>2</sub>),  $q_{\max}^i$  = nameplate power of installation  $i$  (MW),

Recalling the discussion on the opportunity costs for future periods, which show-up with an updating allocations scheme, the individual short-term supply curve must change for this allocation. In our case  $k$  changes as follows:

$$k_r^i = e^i p_r^{CO_2} - a_{r+1}^i p_{r+1}^{CO_2} \quad (3)$$

$a_{r+1}^i$  = average allocation for installation  $i$  in period  $r+1$  (t CO<sub>2</sub>/MWh)

The subtrahend in equation (3) represents the opportunity costs in the updating setting. They are a function of both allocation and allowance price in period  $r+1$ . The allocation in period  $r+1$  in turn depends on the emissions or production respectively (depending on the allocation approach) in period  $r$  and the overall reduction obligation in period  $r+1$ . In the case of the operator not knowing the future he must make assumptions on their magnitude in period  $r$  already.

It is worthwhile to analyse equation (3) in more detail. In combination with (1a) we get for an individual supply curve

$$S_{t,r}^i = (c_r^i + e^i p_r^{CO_2} - a_{r+1}^i p_{r+1}^{CO_2}) q_{t,r}^i \quad (4)$$

One can now see that in the case that the opportunity costs in the next period  $r+1$  are greater than the costs in the period  $r$ , the plant offers at costs which are below its operational costs  $c_r^i$ . Thus, if the following inequality is fulfilled the operator supplies below operational costs:

$$e^i p_r^{CO_2} < a_{r+1}^i p_{r+1}^{CO_2}$$

$$\Leftrightarrow \frac{e^i}{a_{r+1}^i} < \frac{p_{r+1}^{CO_2}}{p_r^{CO_2}} \quad (5)$$

The magnitude of the fracture on the left side is likely to be around 1. However, the right hand side of the inequality is much harder to determine. As it depends on both the present and the future carbon price, the value is a function of absolute price levels as well as the relative difference between prices. Furthermore, we can see that the higher the absolute levels the less relevant the difference between the prices is and the more likely it is that the fraction becomes zero. Figure 3 shows this relationship for selected carbon prices. As one can see, there are price constellations where inequality (5) is fulfilled, especially when future prices are increasing. Thus, we cannot generally conclude whether or not the opportunity for the future allocation is greater than the carbon costs in the present period. Consequently, power prices may increase or decrease.

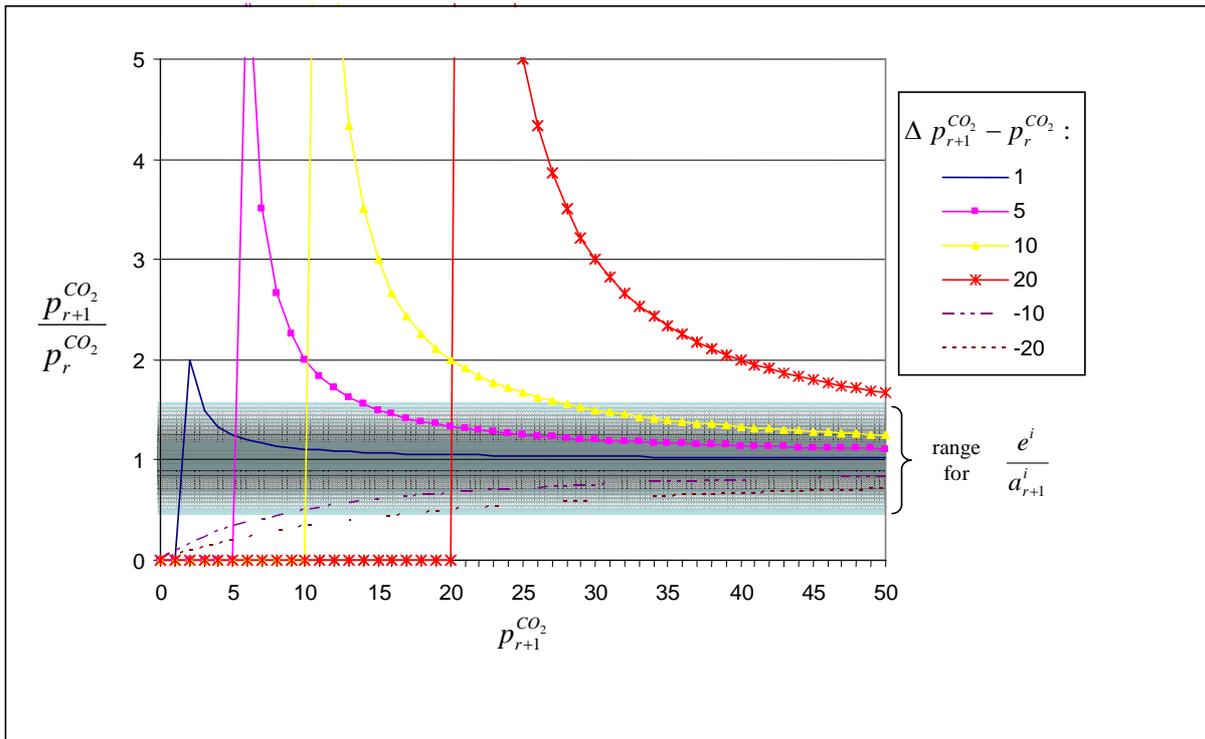


Figure 3: Relationship between absolute and relative carbon prices for present and subsequent trading period

The effect may also be seen if the carbon price is the same for both periods as long as the (expected) allocation  $a_{r+1}^i$  is greater than a plant's emission intensity  $e^i$ . At first glance this

might be considered to be unlikely. However remember that a generation benchmark results in allocation based on output. In this case  $a_{r+1}^i$  is the same for all plants. In contrast  $e^i$  is plant specific. The less emission intensive a plant is the more likely  $e^i \ll a_{r+1}^i$ . Thus, with prices of unity in both periods, low emission intensive plants will supply below operational costs in order to receive more entitlements in the future.

In the context of this analysis it is reasonable to assume that the total budget of entitlements allocated for free is reduced over time and that it is zero at point  $T$  in the future<sup>21</sup>, i.e.

$$A_r (r = T) = 0 \quad (5)$$

where  $A_r$  = total quantity of allowances to be distributed for free in period  $r$

The cumulative supply curve for all allocation options results in the following:

$$S_{t,r} = \sum_i S_{t,r}^i \quad (6)$$

Where  $S_{t,r}$  = cumulative supply in hour  $t$  and period  $r$  (MW)

The demand curve is assumed to be linear, i.e. of the form

$$D_{t,r} = g_{t,r} - b_{t,r} q_{t,r} \quad (7)$$

Where  $D_{t,r}$  = demand in hour  $t$  in period  $r$  (MW),  $g_{t,r}$  and  $b_{t,r}$  = parameters,  $q_{t,r}$  = load in hour  $t$  in period  $r$  (MW)

No storage options are considered. Thus, for each hour the equilibrium is as follows:

$$S_{t,r} = D_{t,r} \quad (8)$$

Only one market considered. No distinction is made between different kinds of consumers (e.g. industrial vs. private consumers). Other costs such as for example transmission fees or taxes are neglected.

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<sup>21</sup> At the same time the quantity of entitlement auctioned may increase.

## Emission targets

The total budget of allowances is given exogenously. It is defined as a percentage of the reference scenario without any policy interventions. The budget is distributed according to different allocation rules.

## The allocation

Only CO<sub>2</sub> emitting plants receive allowances.<sup>22</sup> Four different allocation options are studied. Firstly, I distinguish between an emissions based and a generation benchmark based approach. Secondly, these two options are distinguished as regarding the reference period. It may either be constant and updated. In the former case, emission allowances in both periods are allocated on the basis data of the same reference period. In the latter case the allocation is based on the data of the previous period. Thus, the following four allocation options for a single installation *i* are retrieved:

Emission based constant

$$A_r^i = \frac{\sum_t e_{t,0}^i q_{t,0}^i}{\sum_i \sum_t e_{t,0}^i q_{t,0}^i} * A_r \quad (9)$$

Emission based updating

$$A_r^i = \frac{\sum_t e_{t,r-1}^i q_{t,r-1}^i}{\sum_i \sum_t e_{t,r-1}^i q_{t,r-1}^i} * A_r \quad (10)$$

Generation benchmark constant

$$A_r^i = \frac{\sum_t q_{t,0}^i}{\sum_i \sum_t q_{t,0}^i} * A_r \quad (11)$$

Generation benchmark updating

$$A_r^i = \frac{\sum_t q_{t,r-1}^i}{\sum_i \sum_t q_{t,r-1}^i} * A_r \quad (12)$$

where  $A_r^i$  = allocation to installation *i* in period *r*,  $A_r$  = total quantity of allowances to be distributed for free in period *r*

## Abatement costs

Abatement costs differ among installations. Age and past retrofits are two important factors to be considered in this regard. Regarding the market effect and the implications of different

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<sup>22</sup> Burtraw et al. (2002) allocate allowance to non-hydro renewable sources, i.e. non-emitting plants, too.

allocation rules, abatement costs are not important. For the market analysis, emission intensity and the resulting carbon costs must be considered. The latter are the same for all market players and equal the allowance price. This is why no individual abatement options are considered below.<sup>23</sup> Assuming abatement costs and carbon costs to be of the same magnitude would be realistic in the case where the sector as a whole buys emission allowances on the market.

The assumption of a fixed total allowance budget and a fixed allowance price may seem counterintuitive. One might expect the carbon price to change according to the players' actions. However one has to keep in mind that the allocation can be done on the sector level in a single state<sup>24</sup>. The allowance market however, may comprise both other sectors and other states. Furthermore, additional emission rights from outside the trading scheme might be imported through other mechanisms.<sup>25</sup> In this case the electricity sector in one state can be considered to be a price taker on the allowance market.

### **The overall financial impact**

The overall financial impact consists of two parts: the market effect and the compliance costs. The market effect describes the price change on the electricity market due to the consideration of opportunity costs. As shown above, the price may increase or decrease. The compliance costs result from meeting the emission target. The profit of an installation for period  $r$  can be calculated as follows:

$$P_r^i = \sum_t (p_{t,r} - c_r^i) q_{t,r}^i - (e^i q_{t,r}^i - A_r^i) p_r^{CO_2} \quad (13)$$

Where  $P_r^i$  = profit of installation  $i$  in period  $r$  (EUR)

The second product on the right hand side of the equation constitutes the compliance costs discussed above.

The net present values (*NPV*) for installation  $i$  during the time with a free of charge allocation result in

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<sup>23</sup> Some players, however, might be better off if they can sell allowances on the market.

<sup>24</sup> as for example in European trading scheme

<sup>25</sup> Such as the Clean Development Mechanism

$$NPV^i = \sum_{r=0}^T \left( P_r^i \frac{1}{(1+i)^r} \right) \quad (14)$$

### **Numerical analysis.**

On the supply side, 110 power plants have been introduced. Table 1 gives an overview. Further details can be found in Annex 2. Costs are constant over the two periods. The discount rate is zero.

Table 1: Overview on plants' characteristics<sup>\*)</sup>

Fuel	Number of plants	Average Power (MW)	Average operational costs (EUR/MWh)	Average CO <sub>2</sub> Emissions (t/MWh)
Hydro	10	100	1,900	0,000
Uranium	25	800	5,400	0,000
Lignite	19	350	12,014	1,116
Coal	36	300	15,735	0,885
Natural Gas	19	400	20,318	0,488
Old plants (reserve)	1	10000	25,000	0,409
Total	110	11950	n/a	n/a

<sup>\*)</sup> Based on Balmorel (2001), Bower et al. (2001), Rowland et al. (2003), Leyva et al. (2003), UBS (2003), UCTE (2002), CEC (2004), IEA (2005) and own assumptions

On the demand side, three seasons are distinguished (summer, winter and transition). The two former comprise 90 days each and the latter 180. The load curves are based on UCTE (2002). With these assumptions, total annual energy demand in the reference scenario amounts to 275 TWh/a.

As mentioned above, demand curves are assumed to be linear. As it is generally easier to avoid peak load than to reduce base load demand, two different slopes of the demand curve have been assumed.  $b_{t,r}$  in equation (7) is set to -0.008 for the time between 8 am and 8 pm and to -0.008 for the period from 8 pm to 8 am. As supply and demand match hourly, 24 market equilibria per day are retrieved. This is schematically depicted in Figure 4.

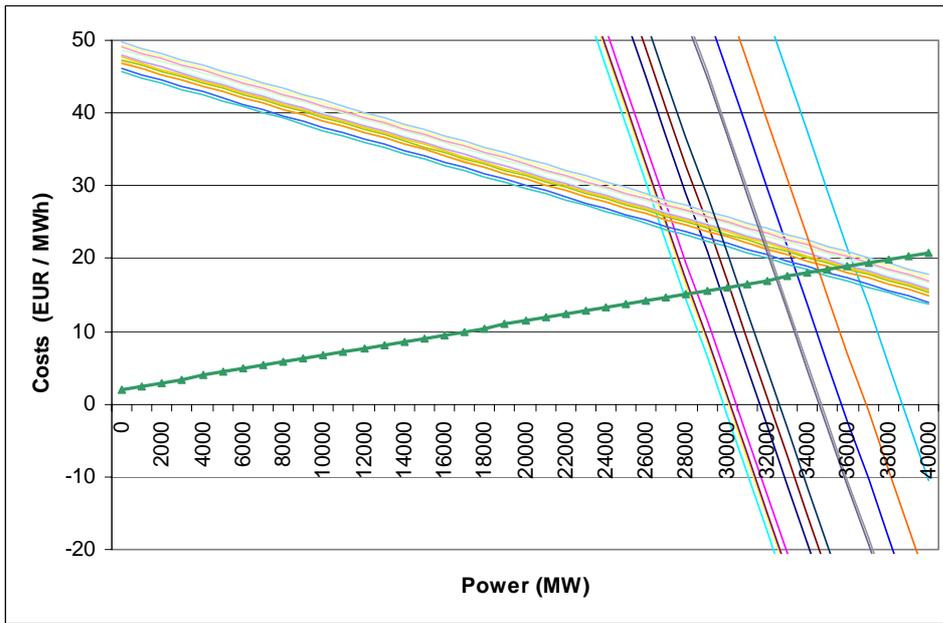


Figure 4: Matching of supply and demand in different hours of the day

There are a lot of studies dealing with the carbon prices for different kinds of trading schemes. An overview of model results is given by Springer (2003). Prices for Annex B trading only CO<sub>2</sub> are reported to range from 3 to 71 US\$/t CO<sub>2</sub>. Allowance prices for the EU trading scheme are about 20 EUR/t CO<sub>2</sub>.<sup>26</sup> Prices for certified emission reductions, which are also eligible within the EU scheme, are about 5 EUR. Against this background different sets of carbon prices are studied.

The emission reduction target is set to 10 % below the aggregate emissions in the reference year for the first and 20 % for the second period respectively.

The expected allocation of the individual plants ( $a_{r+1}^i$  in equation 3) for the second period is determined as the average allocation in period 1 multiplied by a correction factor of 0.8.

<sup>26</sup> See [www.eex.de](http://www.eex.de)

## Results

For a comparison of the different allocation schemes a reference scenario has been defined. In this scenario, no policy intervention takes place. As both allocation options differ considerably regarding the consideration of opportunity costs, the results are presented separately.

### Allocation with a constant basis

Table 2 shows the results on the sector level for major variables for different carbon prices. The results on the level are the same for the two allocation options. As can be seen, the sectors gross margin increase significantly although the production decreases. This is due to the scarcity rents collected by the power operators.

Table 2: Results for constant allocation basis (percentage compared to reference case)

	Price in first / second period (EUR/ t CO <sub>2</sub> )						
	5 / 5	10 / 10	15 / 15	20 / 20	5 / 10	10 / 15	15 / 20
Production (%)	93	87	84	86	90	85	85
Emissions (%)	77	49	29	19	63	39	24
Total gross margin (%)	194	239	277	303	216	258	289
Price change period ref. case -> 1	23,36	44,83	56,78	61,96	23,36	44,83	56,78
Price change period 1 -> 2	0,00	0,00	0,00	0,00	16,95	7,98	2,23

The results differ, however, on plant level. For reasons of simplicity, results are aggregated on fuel-type level in Table 3. As can be seen, plant operators that use natural gas benefit the most. Their gross margin increases to more the 10000 percent of that of the reference case for both options.

Table 3: Average change of gross margin<sup>\*)</sup>

Fuel	Emission based <sup>**)</sup>	Benchmark <sup>**)</sup>	delta (percentage points)	Preferred allocation option
Hydro	207	207	0	indifferent
Uranium	227	227	0	indifferent
Lignite	391	355	36	Emission based
Coal	637	748	-111	Benchmark
Natural gas	12727	15404	-2677	Benchmark

<sup>\*)</sup> based different prices as in Table 2

<sup>\*\*)</sup> percentage compared to reference case

In addition to Table 3 it should be mentioned that lignite-fired plants loose heavily in terms of production but also experience corresponding gains due to the sale of surplus allowances which they do not need after production has decreased. As the base period / generation metric is constant, they can collect this rent eternally.

### **Allocation with updating**

As described above, an allocation with an updating reference period or metric provides different incentives for the plant operators compared to the constant allocation. This is why the results in Table 4 are also given for each period.

As can be seen, the results do not only differ with respect to different carbon prices but also with respect to the allocation options. For price sets where (expected) future carbon price exceed the carbon price in the present period, the decreasing effect on the power price (Figure 2) can clearly be seen. Referring to Figure 3 see also how the price change from the initial to the first period varies depending on absolute and relative carbon prices (line: “Price change period ref. case -> 1(%)”). As demand is elastic, both production and emissions increase in these cases, too.<sup>27</sup>

Table 5 shows the result on the fuel-type level. As the price changes differ for the two allocation options, hydro and nuclear power plant operators now show preferences for the emissions based allocations that distinguish this approach from the former.

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<sup>27</sup> Remember the assumption that the sector as a whole is a price taker and that it cannot influence the carbon price.

Table 4: Results for rolling allocation basis (percentage compared to reference case)

	CO <sub>2</sub> Price*)							
	5 / 5 // 5 / 5	20 / 20 // 20 / 20	10 / 5 // 10 / 10	10 / 5 // 15 / 10	15 / 10 // 20 / 15	20 / 15 // 25 / 20	10 / 5 // 10 / 5	20 / 10 // 20 / 10
<b><i>Emission Based Rolling</i></b>								
Production total (%)	96	89	95	95	92	92	98	96
Emissions total (%)	85	44	78	78	65	57	92	80
Total gross margin (%)	128	209	132	132	157	177	110	120
<u>Period 1 only</u>								
Price change period ref. case -> 1(%)	7,5	31,8	-8,2	-8,2	-0,5	7,1	-8,2	-15,9
Production in period 1 (%)	98	91	102	102	100,3	98	102	104
Emissions in period 1 (%)	94	69	106	106	101	95	106	111
<u>Period 2 only</u>								
Price change period 1 -> 2 (%)	14,6	21,7	58,7	58,7	57,6	50,3	34,9	75,8
Production in period 2 (%)	93	86	87	87	84	86	93	87
Emissions in period 2 (%)	77	19	49	49	29	19	77	49
<b><i>Benchmark Rolling</i></b>								
Production total (%)	96	89	95	95	93	93	98	97
Emissions total (%)	84	41	77	77	62	52	91	80
Total gross margin (%)	126	205	129	129	154	175	107	113
<u>Period 1 only</u>								
Price change period ref. case -> 1(%)	6,19	26,0	-10,5	-10,5	-3,7	3,0	-10,5	-21,0
Production in period 1 (%)	99	92	103	103	101,4	99	103	106
Emissions in period 1 (%)	92	64	105	105	95	85	105	110
<u>Period 2 only</u>								
Price change period 1 -> 2 (%)	15,9	27,0	62,5	62,5	63,1	56,8	38,2	86,4
Production in period 2 (%)	93	86	87	87	84	86	93	87
Emissions in period 2 (%)	77	19	49	49	29	19	77	49

\*) The four prices are: expected price in period 1 for period 2 / price in period 2 // expected price in period 2 for period 3 / price in period 2

Table 5: Average change of gross margin<sup>\*)</sup>

Fuel	Emission based <sup>**)</sup>	Benchmark <sup>**)</sup>	delta (percentage points)	Preferred allocation option
Hydro	129	127	2	Emission based
Uranium	139	136	3	Emission based
Lignite	192	150	42	Emission based
Coal	291	360	-69	Benchmark
Natural gas	6278	14439	-8161	Benchmark

<sup>\*)</sup> based different prices as in Table 4

<sup>\*\*)</sup> percentage compared to reference case

### Allocation with a constant basis vs. updating

After comparing an emission based and a generation benchmark allocation for different base periods / generation metrics, Table 6 provides a comparison of the allocation with a constant basis vs. updating. As can be seen, all plant operators benefit the most in terms of change in gross margin under an allocation with a constant base period / generation metric. These results are different to Bode's (2006, p. 690) who finds other preferences at this stage. The differences can be explained by the neglect of opportunity costs for allowances allocated in the future periods under an updating allocation in that study.

However, within this constant allocation approach option, preferences vary as a function of fuel used. While hydro and nuclear power operators are indifferent, lignite fired power plants increase their gross margin most under an emissions based allocation. Coal and natural gas fired power plants benefit most from a benchmark based approach.

Table 6: Average change of gross margin<sup>\*)</sup>

Fuel	Constant base period / reference metric		Updated base period / reference metric	
	Emission based <sup>**)</sup>	Benchmark	Emission based	Benchmark
Hydro	<b>207</b>	<b>207</b>	129	127
Uranium	<b>227</b>	<b>227</b>	139	136
Lignite	<b>391</b>	355	192	150
Coal	637	<b>748</b>	291	360
Natural gas	12727	<b>15404</b>	6278	14439

<sup>\*)</sup> based on different prices as in table XX

<sup>\*\*)</sup> percentage compared to reference case

<sup>\*\*\*)</sup> bold figures show maximum values

## **Conclusion**

Emission trading offers the opportunity to limit GHG emissions into the atmosphere cost-efficiently. This is one reason why the EU has decided to implement a Europe-wide trading scheme for major emissions sources such as combustion plants with a thermal power larger than 20 MW. However, many detailed design issues have not yet been decided upon. The question of how to allocate emission allowance over time is one of them.

This paper has analysed this point using the electricity sector as an example. Using a stylised power market, four different allocation options have been used to analyse the resulting impact on different types of plants. It turned out that the electricity sector as a whole is likely to benefit from the introduction of the trading scheme as long as the allowances are distributed free of charge. Under the assumptions made, it was found that all operators prefer an allocation based on constant base period / generation metric as their gross margin increases most with this option. Within this approach, preferences vary as a function of the fuel used. The result may serve decision makers in industry and policy during the negotiations on the design of the scheme.

## References

AGE (2001) 'Materialienband zum Zwischenbericht 2001' Arbeitsgruppe Emissionshandel zur Bekämpfung des Treibhauseffektes (German Emissions Trading Group), <http://www.ag-emissionshandel.de>

Ahman, Markus; Burtraw, Dallas; Kruger, Joseph; Zetterberg, Lars (2005) The Ten-Year Rule: Allocation of Emission Allowances in the EU Emissions Trading System, Discussion Paper 05-30, Resources for the Future, Washington.

AGO (1999) 'National Emission Trading' Discussion Paper 1-4, Australian Greenhouse Office, Canberra

Balmorel (2001) 'Balmorel: A Model for Analyses of the Electricity and CHP Markets in the Baltic Sea Region – Main report' retrievable on: [www.balmorel.com](http://www.balmorel.com)

Bode, Sven (2006) Multi-period emissions trading in the electricity sector – winner and losers, in *Energy Policy* 34, p. 680-691

Bode, Sven (2003) 'Abatement Costs vs. Compliance Costs in Multi-Period Emissions Trading' HWWA Discussion Paper No 230

Böhringer, Christoph; Lange, Andreas (2003) 'Economic Implications of Alternative Allocation Schemes for Emission Allowance – A theoretical and Applied Analysis' ZEW Discussion Paper 03-22

Boemare, Cathrine; Quirion, Philippe (2002) 'Implementing greenhouse gas trading in Europe: lessons from the economic literature and international experience' *Ecological Economics* 43 pp. 213-230

Bohm, Peter (2002) 'Comparing Permit Allocation Options: The Main Points' Working Paper in Economics 2002:11, Department of Economics, University of Stockholm

Bower, John; Bunn, Derek W.; Wattendrup, Claus (2001) 'A model-based analysis of strategic consolidation in the German electricity industry' *Energy Policy* 29, pp. 987-1005

Burtraw, Dallas; Palmer, Karen; Paul, Anthony; Bharvirkar, Ranjit (2002) 'The Effect of Asset Values of the Allowance Allocation of Carbon Dioxide Allowances' in: *The Electricity Journal* **15**, No. 5, pp. 51-62

Burtraw, Dallas; Palmer, Karen; Bharvirkar, Ranjit; Paul, Anthony (2001) 'The Effect of Allowance Allocation on the Costs of Carbon Emission Trading' Resources for the Future, DP 01-30

CCAP (2002) 'Design of a Practical Approach to Greenhouse Gas Emissions Trading Combined with Policies and Measures in the EC' Center for Clean Air Policy, retrievable on: [www.ccap.org](http://www.ccap.org)

CCAP (1999) 'Allocation of Greenhouse Gas Reduction Responsibilities Among and Within the Countries of the European Union' Center for Clean Air Policy, retrievable on: [www.ccap.org](http://www.ccap.org)

CEC (2004) North America Power Plant Air Emissions, Commission for Environmental Cooperation of North America, Montréal, Canada

COM (2003) 'External Costs - Research results on socio-environmental damages due to electricity and transport' European Commission, Directorate-General for Research, Brussels

COM (2001) 'Greenpaper on Greenhouse Gas Emission Trading within the European Union, Summary of Submission' 14 May 2001, Retrievable on [http://europa.eu.int/comm/environment/docum/0087\\_summary.pdf](http://europa.eu.int/comm/environment/docum/0087_summary.pdf)

Cramton, Peter; Kerr, Suzi (2002) 'Tradable permit auctions How and why to auction not grandfather' *Energy Policy* **30**, pp. 333-345

EU (2003) 'DIRECTIVE 2003/87/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC' *Official Journal of the European Union*, 25. 10. 2003, p. 32-46

FIELD (2000) 'Designing Options for Implementing an Emissions Trading Regime for Greenhouse Gases in the EC' Final Report, Foundation for International Environmental Law and Development, retrievable on: [www.field.org.uk](http://www.field.org.uk)

Fischer, Carolyn (2001) 'Rebating Environmental Policy Revenues: Output-Based Allocations and Tradable Performance Standards' Resources for the future, Discussion Paper 01-22

Goulder, Lawrence H. (2002) 'Mitigating the Adverse Impacts of CO<sub>2</sub> Abatement Policies on Energy-Intensive Industries' Resources for the Future, Discussion Paper 02-22

Hauch, Jens (2003) 'Electricity trade and CO<sub>2</sub> emission reductions in the Nordic Countries' *Energy Economics* **25**, pp. 509-526

Holmes, K. John; Friedmann, Robert M. (2000) 'Design alternatives for a domestic carbon trading scheme in the United States' *Global Environmental Change* **10**, pp. 273-288

IEA (2005) Projected Costs of Generating Electricity, International Energy Agency, Paris, France

Leyva, Enrique de Leyva; Lekander, Per A. (2003) 'Climate Change for Europe's Utilities' The McKinsey Quarterly, 2003 Number 1 retrievable on:  
[http://www.mckinseyquarterly.com/article\\_page.asp?ar=1265&L2=8&srId=69](http://www.mckinseyquarterly.com/article_page.asp?ar=1265&L2=8&srId=69)

MIES (2000) 'Implementing an Emissions Credits Trading System in France to Optimize Industry's Contribution to Reducing Greenhouse Gases (Final)' MIES – Industry Working Group

Munksgaard, Jesper; Ramskov, Jacob (2002) 'Effects of internalising external production costs in a North Europe power market' *Energy Policy* **30**, pp. 501-510

Nera (2002) 'Evaluation Of Alternative Initial Allocation Mechanisms In A European Union Greenhouse Gas Emissions Allowance Trading Scheme' National Economic Research Associates

NZME (1998) 'Technical Design Issues for a Domestic Emissions Trading Regime for Greenhouse Gases: A Working Paper' Ministry for the Environment (New Zealand), retrievable on: <http://www.mfe.govt.nz/about/publications/climate/climatechange.htm>

Parry, Ian W. H. (2002) 'Are tradable Emissions Permits a Good Idea?' Resources for the Future, Issues Brief 02-33

Pashigian, B. Peter (1995) *Price Theory and its Applications*, McGraw-Hill Inc., New York

PwC (2003) 'Allowance allocation within the Community-wide emissions allowance trading scheme', PriceWaterhouseCoopers, Utrecht

Rowland, Chris; Anderson, Geraint; Brough, Martin; Cepeda, Julian; Font, Ignacio; Garrido, Javier; Hawkins, Simon; Patel, Ajay; Schumacher, Lueder (2003) 'Emission Trading – Carbon Derby' Dresdner Kleinwort Wasserstein Security Ltd., London

Rehdanz, Katrin; Tol, Richard (2004) On multi-period allocation of tradable emission permits, Working Paper FNU-43.

Sijm, J. P. M; Bakker; S. J. A; Chen, Y.; Harmson, H. W., Lise, W. (2005) 'CO<sub>2</sub> price dynamics: the implications of EU emissions trading for the price of electricity', ECN-C-05-081, Energy research Center of the Netherlands.

Speck, Stefan (1999) 'Energy and carbon taxes and the distributional implications' *Energy Policy* **27**, pp. 659-667

Springer, Urs (2003) 'The market for tradable GHG permits under the Kyoto Protocol: a survey of model studies' *Energy Economics* **25**, pp. 527 –551

Stavins, Robert, N. (2003) 'Market-Based Environmental Policies: What can we learn from U.S. Experience (and Related Research)?' Resources for the Future, DP 03-43

UBS (2003) 'German electricity wholesale market' UBS Investment Research, October 16, 2003

UCTE (2002) 'Statistical Yearbook 2002, Union for the Co-ordination of Transmission of Electricity' retrievable on [http://www.ucte.org/publications/library/e\\_default\\_2002.asp](http://www.ucte.org/publications/library/e_default_2002.asp)

UNEP and UNCTAD (2002) 'An emerging market for the environment: A Guide to Emissions Trading' United Nations Publication, first edition 2002

Woerdman, Edwin (2000) 'Organizing emissions trading: The barrier of domestic permit allocation' *Energy Policy* **28**, pp. 613-623

WBCSD (2001) 'The Greenhouse Gas Protocol – a corporate accounting and reporting standard' World Business Council for Sustainable Development, Conches-Geneva

UNFCCC (2005) KEY GHG DATA, retrievable on:

[http://unfccc.int/files/essential\\_background/background\\_publications\\_htmlpdf/application/pdf/key\\_ghg\\_data\\_web.pdf](http://unfccc.int/files/essential_background/background_publications_htmlpdf/application/pdf/key_ghg_data_web.pdf)

## Annex

How does a benchmark based allocation work?

In this analysis the term “benchmark” is used in the sense of a specific emission factor, i.e.

$$\frac{\textit{emissions}}{\textit{output}} \quad ^{28}$$

The allocation based on a general benchmark could be calculated as follows

$$A_r^i = s_{r-j} q_{r-j}^i \quad (10)$$

where  $A_r^i$  = allocation to installation  $i$  in period  $r$ ,  $s_{r-j}$  = benchmark in period  $r-j$ ,  $q_{r-j}^i$  = output of installation  $i$  in period  $r-j$

An alignment between a bottom-up (benchmark) approach and a top-down constraint as set by the Kyoto targets requires the consideration of the constraint given in inequality (6). A straightforward approach would be the introduction of a period-specific correction factor  $c_r$  as discussed for example in PwC (2003) and AGE (2001)

$$c_r = \frac{A_r}{\sum_i A_r^i} \quad (11)$$

Taking into account this factor, (10) changes to

$$\begin{aligned} A_r^i = s_{r-j} q_{r-j}^i c_r &\Leftrightarrow A_r^i = s_{r-j} q_{r-j}^i \frac{A_r}{\sum_i A_r^i} \Leftrightarrow A_r^i = s_{r-j} q_{r-j}^i \frac{A_r}{\sum_i s_{r-j} q_{r-j}^i} \\ \Leftrightarrow A_r^i &= \frac{q_{r-j}^i}{\sum_i q_{r-j}^i} A_r \end{aligned} \quad (12)$$

$A_r$  = total quantity of allowances to be distributed in period  $r$

As one can see, a benchmark based allocation which takes into account the national budget (e.g. the Kyoto Commitment), results in an individual allocation which is only proportional to a participant's output in a certain period and not at all related to emission intensities. This might be somewhat surprising as the intention of the use of a benchmark is generally to consider the specific emissions.<sup>29</sup>

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<sup>28</sup> Theoretically, any benchmark as, for example, labour productivity or turnover could be used for allocation. For an emission benchmark, other reference figures than the output could also be used.

<sup>29</sup> Compliance costs may of course differ.