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**A Top-down and Bottom-up look at Emissions Abatement
in Germany in response to the EU ETS**

by

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08-017

November 2008

**A Joint Center of the Department of Economics,
MIT Energy Initiative, and Sloan School of Management**

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Abstract:

This paper uses top-down trend analysis and a bottom-up power sector model to define upper and lower boundaries on abatement in Germany in the first phase of the EU Emissions Trading Scheme (2005-2007). Long-term trend analysis reveals the decoupling of economic activity and carbon emissions in Germany that has occurred since 1996 and has accelerated since 2005, in response to rising commodities prices, the introduction of a carbon trading, and other measures undertaken in Germany. Differing emission intensity trends and emissions counterfactuals are constructed using emissions, power generation, and macroeconomic data. Resulting top-down estimates set the upper bound of abatement in Phase I at 121.9 mn tons for all EU-ETS sectors and 56.7 mn tons for the power sector only. Using the tuned version of the model “E-simulate” a lower boundary of Phase I abatement is established at 13.2 million tons, based only on fuel switching in the power sector, which constitutes 61% of German ETS sector emissions. The paper characterizes abatement, critically discusses the underlying assumptions of the outcomes, and examines the impact of two main factors on power sector abatement, namely price and load.

I. Introduction and Methodology

Germany is the largest and most complex economy in the European Union and the largest emitter of CO₂ in the EU's Emissions Trading Scheme, accounting for about 25% of the program's coverage of annual emissions of approximately two billion metric tons. Thus, what happens in Germany significantly influences the EU ETS.

This paper addresses what reduction in German CO₂ emissions can be reasonably inferred in response to the carbon price that existed during the trial period extending from 2005 through 2007. Since reductions can be estimated only by comparison of actual emissions with what emissions would have been absent the EU ETS and the CO₂ price associated with it, analysts are forced to estimate this unobserved counterfactual. In this paper, upper and lower bound estimates are provided by an application of the top-down trend analysis used by Ellerman and Buchner (2008) for the EU as a whole and a bottom-up approach focused on the power sector using the simulation model applied to the EU as a whole in Delarue et al. (2008).

The top-down approach is based on trends in economic activity, emissions, and emission intensities that require an analysis of these trends prior to the start of the EU ETS on January 1, 2005. Essentially, this approach assumes a continuation of these trends in the absence of a carbon price. Particular attention is given to the trends in emissions intensity for various indicators of economic activity. Since the economic activity and emissions can be observed ex post, construction of the counterfactual proceeds by assuming that the observed pre-policy trend in emissions intensity would have continued and by multiplying the predicted values for intensity by observed levels of economic activity to obtain counterfactual emissions. The difference from that level of emissions to what is observed with the carbon price constitutes the top-down estimate of abatement. Implicitly, this approach assumes that everything else would have been the same; and this is rarely the case. Accordingly, any complete analysis requires consideration of other factors affecting emissions that have changed from the pre-policy period. Examples are fuel prices and renewable energy policy. As will be explained, at least some of the abatement that can be inferred by this top-down approach cannot be attributed to the carbon price. Hence, this estimate forms an upper limit on abatement.

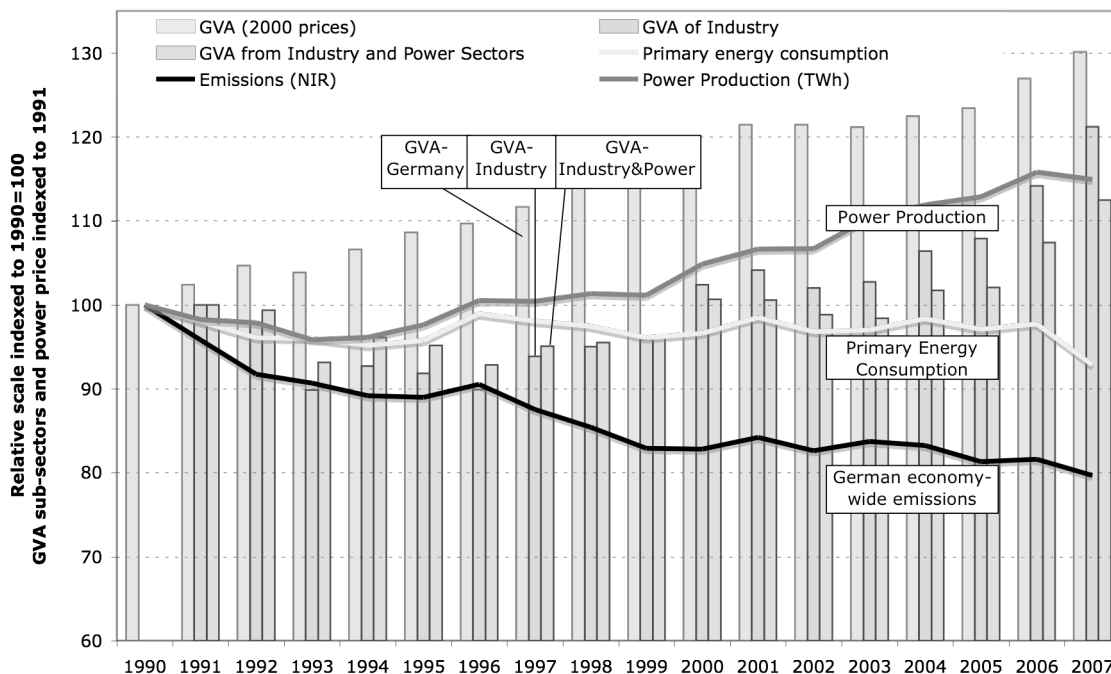
For a lower limit estimate, the paper focuses on the power sector alone, which constitutes 61% of the CO₂ emissions within the sectors included in the EU Emissions Trading Scheme in Germany. It is widely acknowledged (and implicit in the windfall profits critique) that power companies priced the value of CO₂ into their bids for supplying electricity to the grid. The additional carbon cost in the electricity supply bids would change the dispatch of power plants depending on their type and the availability of lower emitting (generally natural gas fired) plants to substitute for higher emitting (generally coal) plants at various times throughout the year. The availability of lower-emitting generation for such fuel switching depended heavily on fuel prices and the load at particular hours. To make this estimate, a model that simulates the operation of the German power sector as part of the European grid and that resolves supply on an hour-by-hour and plant-by-plant basis was used with actual demand and fuel prices, both of

which are assumed to be independent of the carbon price. The difference between simulations with and without the actual CO₂ price provides a bottom-up estimate of abatement in the German power sector. Since it is likely that other sectors reduced emissions to some extent in response to the CO₂ price, this estimate must be considered a lower bound. Also, the simulation model would not capture other effects of the carbon price, such as lower demand for electricity or improved efficiencies in power plants in response to the higher fuel/carbon price.

II. Longer term trends in German economic activity, energy use, and emissions

Long-term trends of re-unified Germany can only go back to 1990. Even then, the observed trends reflect historical events that will not recur. For instance, the unification of East and West Germany in 1990 began a process of industrial reorganization and consolidation of the former socialist Eastern Germany that had a marked effect on measured economic activity, and more particularly on energy use and emissions, as illustrated in Figure 1.

Figure 1: Macro-economic indicators, power prices and emissions since 1990



Source: German government, CRF reports

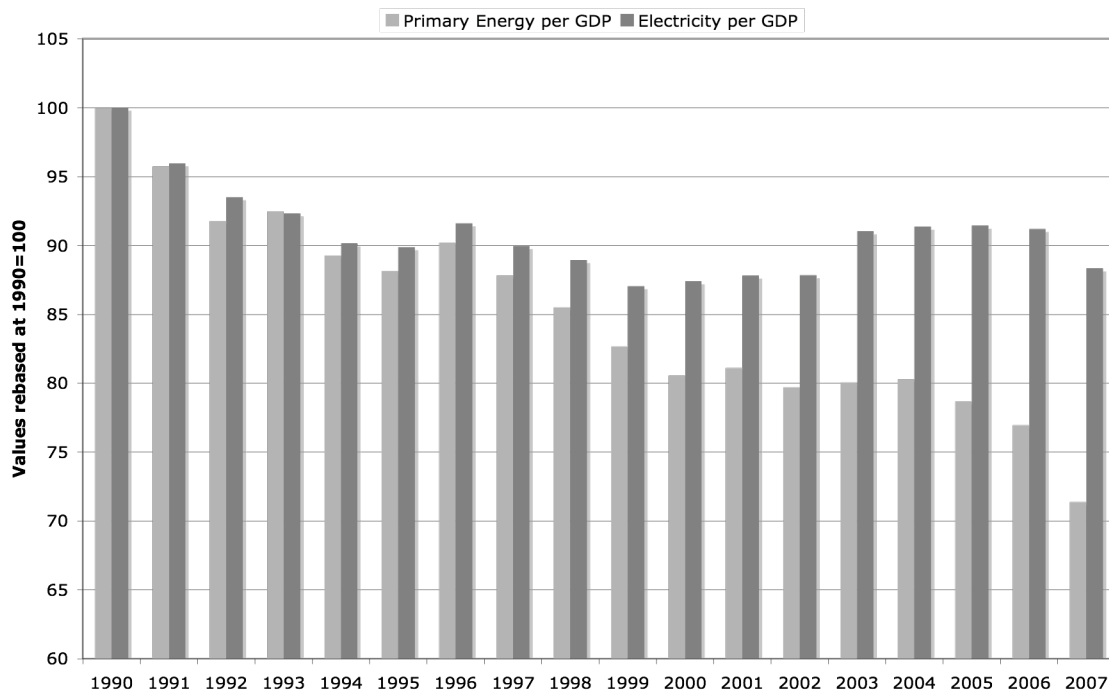
From 1990 to 1996, economy-wide CO₂ emissions were reduced by 10% and this coincided with a comparable reduction in industrial activity as measured by the gross value added (GVA) of the industry component of the national income statistics. Primary energy consumption and power production fell by about 5% during this period, although by 1996, power production was back to the 1990 level and primary energy consumption was almost there. In contrast, industrial activity and economy-wide CO₂ emissions

remained about 10% below the 1990 level. During this period, economic activity for re-unified Germany, as reflected by gross value added (GVA) for all components of national income, was increasing and by 1996, it stood at 10% above the 1990 level. The difference in the trends for the economy as a whole and for industrial activity reflects the effect of the modernization and closure of state-owned industrial production sites in East Germany, which also had a marked one-time effect on CO₂ emissions.

1996 marks a turning point: from then on, industrial activity rose more or less steadily, as did power production and GVA for the economy as a whole. Notably however primary energy consumption remained flat, before a marked reduction in 2007, and economy-wide CO₂ emissions continued to decline. A particularly notable feature of the post-1996 period is the recovery of industrial activity, especially in the three years that marked the trial period. From 1996 through 2004, constant dollar GVA in the industrial sector excluding construction and power increased at an annual rate of 2.1%. From 2004 through 2007, the annual rate of increase was 4.4%. The carbon emissions that were associated with this increase were by and large included in the EU ETS, although the sub-sectors accounting for the extra growth, machine tools, electronics and optics, are not especially carbon intensive.

Two longer term trends set the stage for focusing on the EU ETS emissions. The first is that, while both energy and electricity use per unit of constant-dollar GDP declined from 1990 through 1999 at 2.1% and 1.5% respectively, they have diverged notably since 1999, as shown in Figure 2.

Figure 2: Primary Energy and Electricity Intensity per GDP

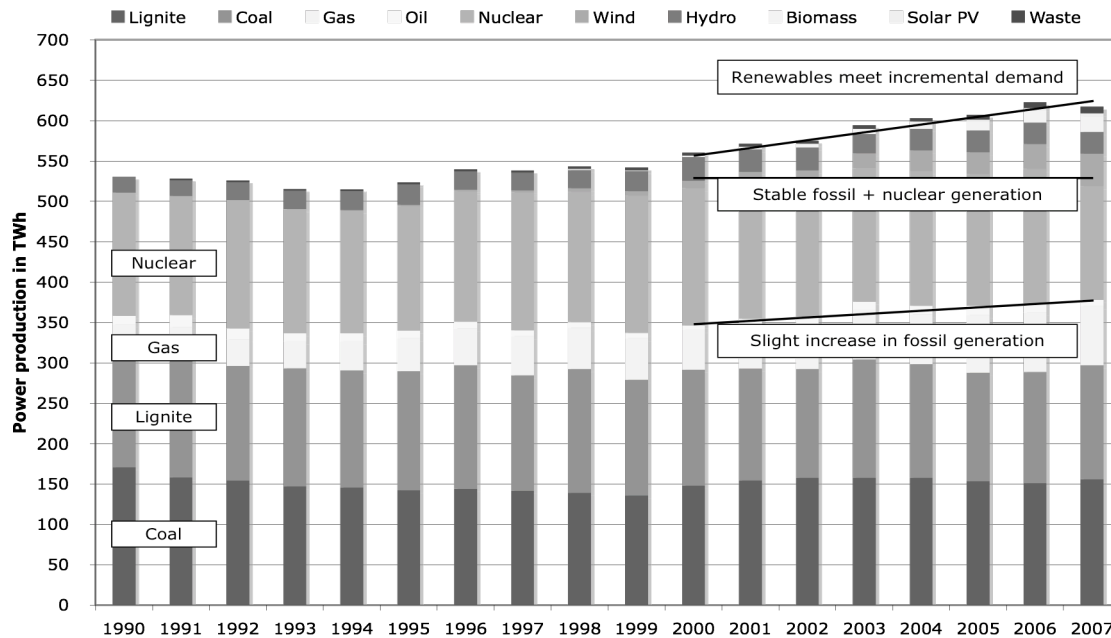


Source: German Government

Energy use per unit of GDP stagnated at 2000 levels until 2004 before continuing a 2% annual decline in 2005, 2006 and a sharp 7% decline in 2007. Overall, this measure of intensity has continued to decline at the 1990s rate of about 2.0% per annum. In contrast, electricity use per unit of GDP stopped declining in 1999 and rose steadily through 2006 before a 3% drop in this intensity indicator in 2007, which has almost returned this index to its 1999 level.

The second trend of note concerns the composition of electricity generation in the German power sector. In particular, fossil generation, which had fallen by 6% between 1990 and 1999, has since risen by 12% in 2007, about half of which was lignite and the other half natural gas. In part, this trend reflects the fact that electricity use is increasing apace with GDP, but it also reflects the decline in nuclear generation. As shown in Figure 3, the level of generation from combined nuclear and fossil generation has increased only very slightly since 1999 (+2.2%). The contemporaneous nearly 14% increase in demand has been met almost entirely by renewable energy. The increased fossil generation has made up for the 17% reduction in nuclear generation, which is presumably a reflection of the German government decision in 2000 to phase out nuclear power.

Figure 3: German power generation by fuel type

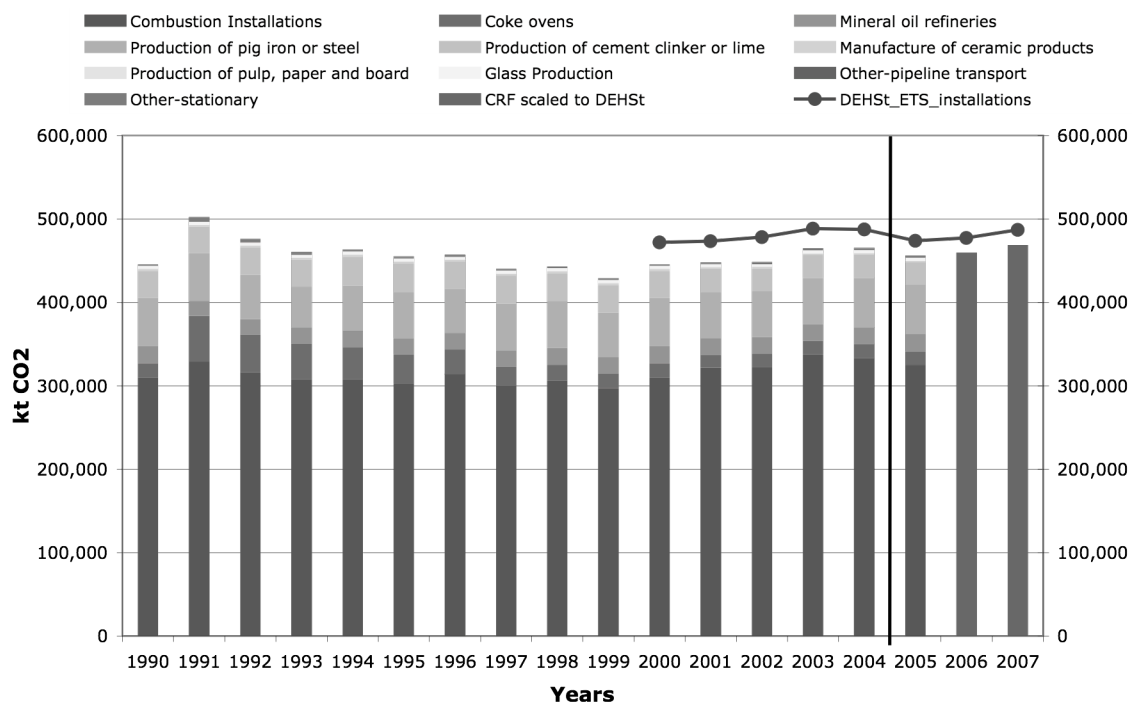


Source: German government, CRF reports

Focusing on the EU ETS Sectors

Forming a counterfactual estimate of emissions from the EU ETS sectors is complicated by the fact that data for these installations was not collected prior to the EU ETS. Nevertheless, two sources are available and they largely agree where they overlap. The first source is the series of National Inventory Reports submitted to the United Nations in the Common Reporting Format (CRF) by Germany for its GHG emissions since 1990. Although EU ETS sectors are not identified as such in these reports, they are sufficiently detailed that a time series can be approximated by aggregating the sub-sectors that most closely reflect the EU ETS installations. The second source is the German emissions trading authority (DEHSt), which has published the aggregate emissions of the German installations included in the EU ETS since 2000 as collected in the process of preparing the first National Allocation Plan and subsequently verified. These two series are presented in Figure 4.

Figure 4: Emissions from EU-ETS relevant sub-sectors of German CRF data



Source: German CRF, DEHSt

As can be readily seen, for the years when the two sets of data overlap, 2000-2005, the series move together. The DEHSt series is consistently about 5% higher than the series reconstructed from the UN CRF data, but both show rising emissions from 2000 through 2004 and a noticeable dip in emissions in 2005, the first year of the EU ETS. This close correspondence provides the basis for the estimated UN CRF data for 2006 and 2007, since these latter are published with a two-year lag, and for assuming that the pre-2000 UN CRF data provide a reasonable estimate of the changes in emissions that would have occurred if the same types of installations had been included in the EU ETS in the 1990s.

Both sets of data suggest that EU ETS emissions were rising from 1999 through 2004, in line with trends in the power sector and the surge in industrial output and unlike CO₂ emissions for the Germany economy as a whole, which declined very slightly over the same period of time. Thus, the appropriate trends to use for projecting counterfactual emissions for the EU ETS sectors during the trial period are those that have emerged since 2000, not those that incorporate the one-time changes in energy use that were associated with the re-unification of Germany.

III. Top-down estimate of Abatement

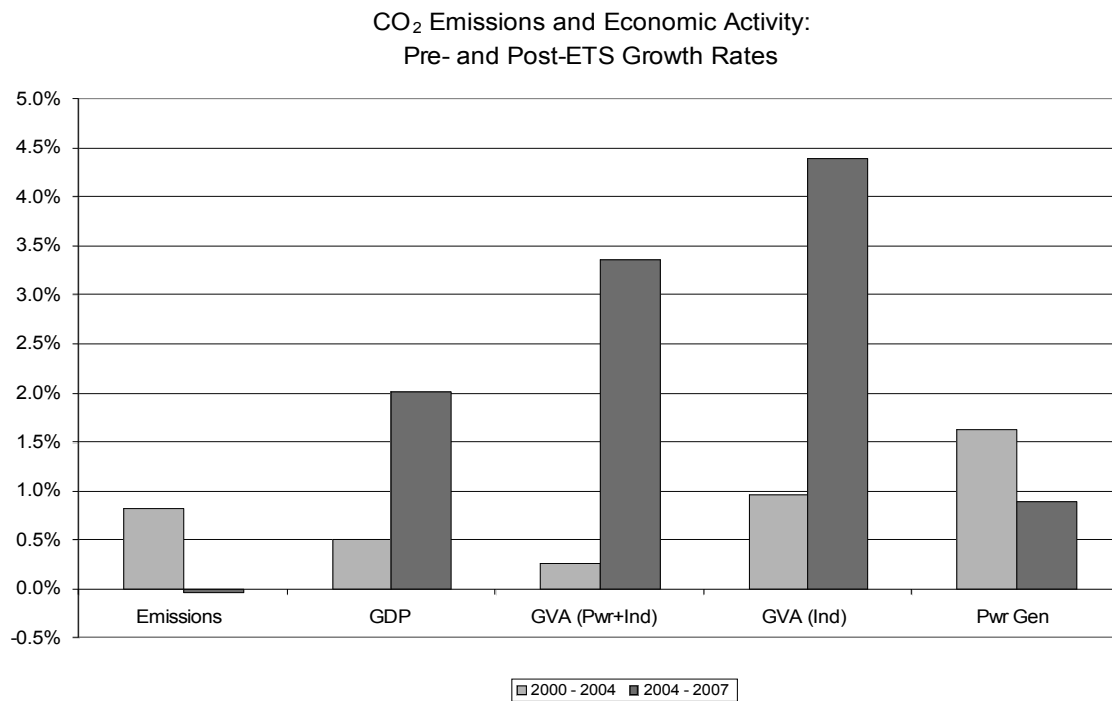
Top-down estimates of abatement, such as those first essayed for the EU ETS by Ellerman and Buchner (2007), rely upon aggregate data and comparison of trends before and after some policy measure is implemented. Typically, the analyst is looking for some break in the trend that could indicate that the policy had an effect. As an ex post exercise, the analyst also has the advantage of knowing the evolution of other factors that would cause emissions to be higher or lower independently of the policy measure, or in this case, the price of CO₂ as expressed in European Union allowances (EUAs).

Obviously, much depends on the choice of trend. The evolution of emission levels is not necessarily helpful since it can be influenced by these other factors. For instance, if economic activity were to decline at the time the policy measure is being introduced, emissions would be expected to be lower anyway. Attributing the emission reduction to the policy measure would not be warranted, or at the least it would constitute an overstatement of the measure's effect.

An important assumption in evaluating the effect of some policy measure is that the pre-policy trend in CO₂ intensity, and specifically of CO₂ emissions associated with various indicators of economic activity, would have continued absent the policy measure. Intensity is not fixed; it will vary from year to year as a result of fluctuations in weather, energy prices, and the composition of economic activity. Nevertheless, the extrapolated values can be seen as an expectation that can be adjusted to the extent these other factors and their effect on intensity are known.

The effect of the policy is measured by difference from what is observed and the counterfactual projection of the pre-policy trend into the policy period. Thus, counterfactual emissions would be the projected pre-policy intensity trend times the observed ex post indicator of economic activity. The difference from observed emissions—which are presumed to reflect the CO₂ price (or other policy measure)—provides the estimate of abatement. Figure 5 provides the basic elements of such an analysis of the effect of the EU ETS on Germany's CO₂ emissions.

Figure 5: Emissions and Economic Activity Growth Rates



Source: German Government, DEHSt

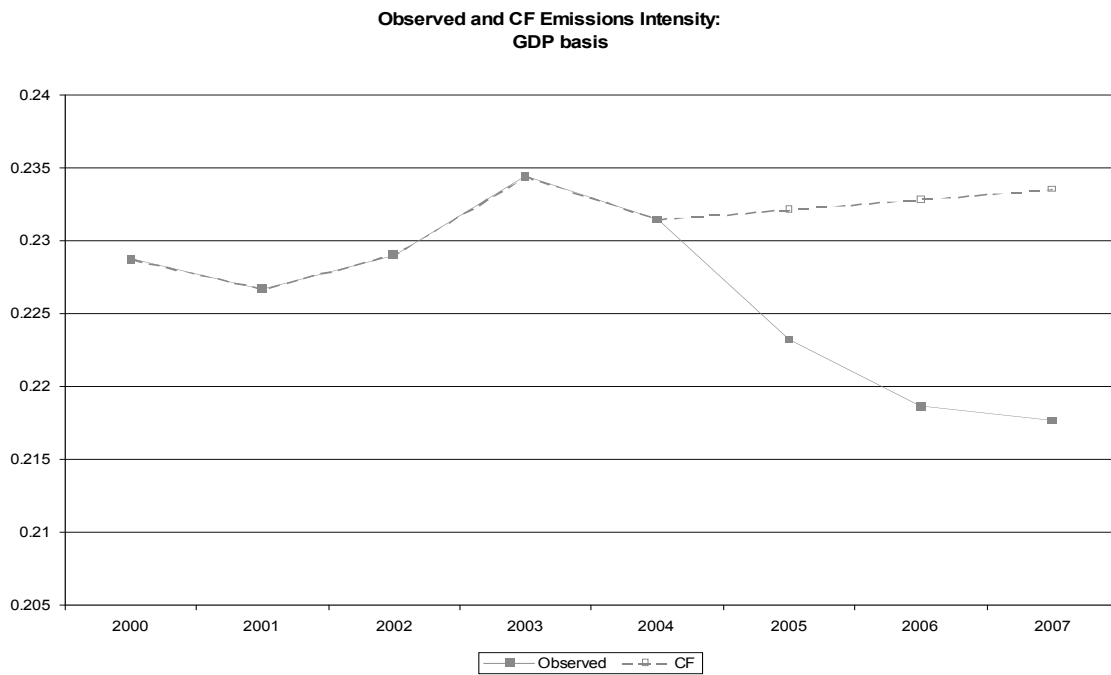
The pairs of columns provide the annual rates of growth for CO₂ emissions and four indicators of economic activity for the four years preceding the introduction of the EU ETS (2000-2004) and for the three years of the trial period (2004-2007). The four indicators of economic activity are gross domestic product (GDP), a common measure of activity for the economy as a whole, gross value added (GVA) for the sectors of the economy included in the EU ETS (mostly, electricity generation and industrial activities), GVA for industrial activities alone, and power generation (which is measured in physical units instead of GVA). GDP includes more economic activity than is encompassed by the EU ETS, but it is a readily available and commonly used indicator that is thought to have an important influence on CO₂ emissions. The GVA of the combined power and relevant industrial components of GDP comes closest to capturing the EU ETS sectors, although it would miss combustion facilities greater than 20 MW thermal that are located in sectors not included in the EU ETS. The GVA for industry alone and the generation of electricity reflect the activity levels of the two main subcomponents of EU ETS emissions.

The striking feature of Figure 5 is the change in the growth in CO₂ emissions before and after the EU ETS in contrast to the corresponding changes for the several indicators of economic activity. In the four years prior to the introduction of the EU ETS, CO₂ emissions grew at an annual rate of about 0.8% per annum; in the three years since the introduction of a CO₂ price, emissions have declined very slightly. This change of trend in the absolute level of emissions is remarkable given the marked acceleration of economic activity in Germany during the EU ETS period in contrast to the pre-policy period. For instance, GDP grew at an annual rate of about 0.5% from 2000 to 2004, but at

the much higher rate of 2.0% per annum for the first three years of the EU ETS. An even more dramatic acceleration in economic activity can be observed for the two, progressively narrower subcomponents of GDP. There was a slight deceleration in the rate of growth of power generation, from about 1.6% to 0.9% annually, but there was still significant growth. Looking across the first column of each pair, the increase of CO₂ emissions from 2000 to 2004 seems completely in keeping with the increases in economic activity indicated by the four indices. That connection is totally broken in comparing the second columns of each pair. If the pre-policy trend in intensity had continued, CO₂ emissions would have grown at an even greater rate than observed from 2000 to 2004. Instead, the emission level held steady.

The change from what might have been expected, absent the CO₂ price, and what was observed is presented in Figure 6, which shows both the evolution of observed CO₂ intensity per unit of GDP from 2000 through 2007 and, with the dashed line, what might have been expected from a continuation of the 2000-2004 trend into the policy period.

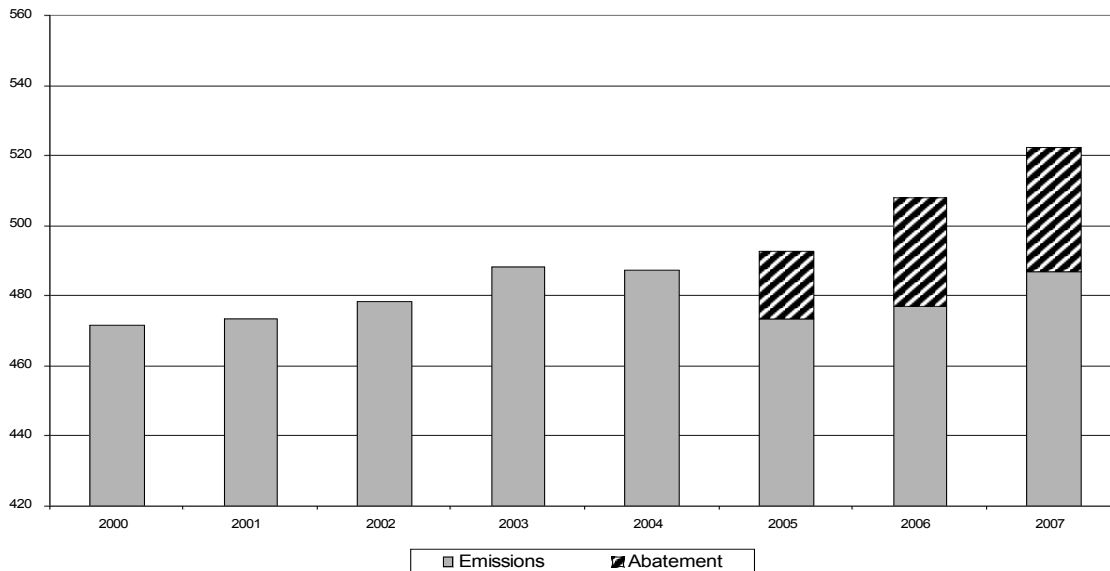
Figure 6: Observed and Counterfactual Emissions Intensity



Source: German government, DEHSt

The intensity observed during the policy years of 2005-2007 is not only below the trend but also below the intensity levels observed in any of the earlier years. Figure 7 projects ETS emissions assuming that the growth in economic activity and the trend in CO₂ intensity were the same within the ETS sectors as they were for the Germany economy as a whole. Actual ETS emissions are also shown and the hatched area represents the top-down estimate of abatement.

Figure 7: German Emissions and Estimated Abatement for all ETS sectors based on GDP CO₂ intensity



Source: DEHSt

The distinct flattening of emissions growth observed in 2005-2007 may have had some other contributing factors, but it is hard to imagine that the CO₂ price did not play a role, given the general belief that economic activity and CO₂ emissions are closely linked. The yearly pattern that is observed during these years is precisely what economic theory would predict. There was a perceptible drop in emissions as the CO₂ price was integrated into production decisions. Once that adjustment was made emissions continued to grow in some relation to GDP growth. In Germany, CO₂ emissions declined by 2.8% from 2004 to 2005 when real GDP rose by 0.8%. In subsequent years of the trial period, emissions rose by 0.8% and 2.0% while GDP rose by 2.9% and 2.5%. If the pre-policy emissions trend had prevailed, CO₂ emissions would have increased by 1.1%, 3.2% and 2.8% in those three years, at rates that were slightly greater than the rate of GDP growth, as had been the case during the 2000-04 period.

Anyone familiar with the evolution of EUA prices over the years 2005 through 2007 will question why the abatement indicated in Figure 7 would be greater in 2007, when the EUA price was near zero, than in 2005 or 2006, when an average price near €20 prevailed. In response, two reasons can be adduced for placing less confidence on the annual amounts than in the estimate for the period as a whole. First, the estimates reflect a straight line projection of the pre-2005 intensity trend, as readily seen in Figure 6, when in fact the actual counterfactual intensity may have been higher or lower depending on weather and other factors. Such annual variation can be readily seen for the years 2000-2004 around a back-casting of the intensity trend. Thus, in the absence of a carbon price, the counterfactual intensity could have been higher in 2005 and 2006 than shown on Figure 6. In fact, given the succession of two colder than normal winters in 2004-05 and in 2005-06 and an intervening warmer than usual summer, not to mention very high natural gas prices, a higher counterfactual intensity is likely. This would imply greater

abatement. Moreover, the opposite weather conditions and lower natural gas prices occurred in 2007 and could have caused the counterfactual intensity in 2007 to be lower.

A second reason for focusing on the three years as a whole is the departure of reality from many of the assumptions common in economic reasoning. Not all investments in abatement are reversible so that emission reductions effected at the relatively high EUA prices in 2005 and 2006 with an eye to the expected (and realized) higher 2008 CO₂ price would not be shut down or reversed when the EUA price fell temporarily to zero in 2007. Examples of irreversible and reversible abatement can be found in the power industry. Improvements in the efficiency of power generation that may have been realized in 2005 and 2006 with a view to the longer-term EUA price would not have been reversed in 2007. Similarly, contract considerations and the common lags in production decisions would be other reasons not to expect an exact correspondence between carbon prices and abatement. That being said, the more intensive utilization of gas-fired power plants at the expense of coal-fired units for supplying the spot market is readily reversible so that a greater reliance on coal-fired generating units, and commensurately less abatement, would be expected in 2007 as the EUA price fell.

These considerations suggest that some confidence can be placed in the cumulative totals yielded by this type of top-down analysis without being overly concerned about the annual distribution of abatement. Accordingly, Table 1 presents four alternative estimates of CO₂ emissions abatement in Germany due to the EU ETS. The data and representative calculations made to arrive at these estimates are presented in the appendix of this paper. The counterfactuals are based on emissions intensities that are formed by dividing carbon emissions by an observed activity index (such as GDP) over the years 2000-2004 and then extrapolating this intensity into the years 2005-2007. The difference between the emissions counterfactual and actual observed emissions forms the estimate for emissions abatement. The abatement estimate for all EU-ETS sectors uses a counterfactual based on gross value added (GVA) for the industry and power sectors since it most closely matches the EU-ETS sectors; the calculation is also done using emissions intensities based on economy-wide GDP which is an intuitive, but less accurate measure. The power sector abatement uses counterfactuals based on power generation and GDP.

Table 1: Emissions Abatement Estimates

Basis of estimate (million tons)	3-yr abatement	Annually (% reduction)
All ETS Sectors using counterfactual based on GVA Intensity	121.9	40.6 (8.1%)
All ETS Sectors using counterfactual based on GDP Intensity	85.5	28.5 (5.7%)
Power sector only using counterfactual based on generation intensity	45.7	15.2 (3.0%)
Power sector only using counterfactual based on GDP Intensity	56.7	18.9 (3.8%)

Source: Authors' calculations

These estimates vary according to the denominator that is chosen to form the intensity statistic. For example, because the GVA of the sectors included in the EU ETS rose more rapidly than GDP, basing the estimate on the GVA intensity would indicate more abatement. The important point is not the exact number but the general magnitude. The data on emissions and economic activity in Germany all point to emission reductions coinciding with the introduction of the EU ETS and probably caused by the CO₂ price. The numbers developed here would suggest abatement of 5%, and perhaps higher, of what CO₂ emissions from EU ETS installations in Germany would reasonably otherwise have been (around 500 million tons).

There are reasons that these numbers may overstate the magnitude and for that reason we refer to them as upper-bound estimates. For instance, all energy prices rose significantly during these years independently of the CO₂ price, and these increases would have led to reductions in emissions for the same reasons that we would expect a CO₂ price to have an effect. Similarly, the German government has undertaken a series of measures aimed at reducing energy use and these probably led to energy use and emission reductions independently of the EU ETS. Still, it is doubtful that all of the indicated reduction in CO₂ emissions could be attributed to these other confounding factors.

IV. Estimating and illustrating abatement in the power sector

Top-down approaches that depend on aggregate statistics can be supplemented by more focused analyses that concern single sectors where models and data are available. These analyses incorporate more of the sector-specific details that cannot be captured in aggregate numbers and which always raise questions about the reliance that can be placed on top-down estimates. In conducting evaluations that focus on sector-specific details, the analyst can provide another perspective that can be used to support or qualify the results from a top-down approach. Such is the purpose of this section which focuses on fuel switching in the German power sector.

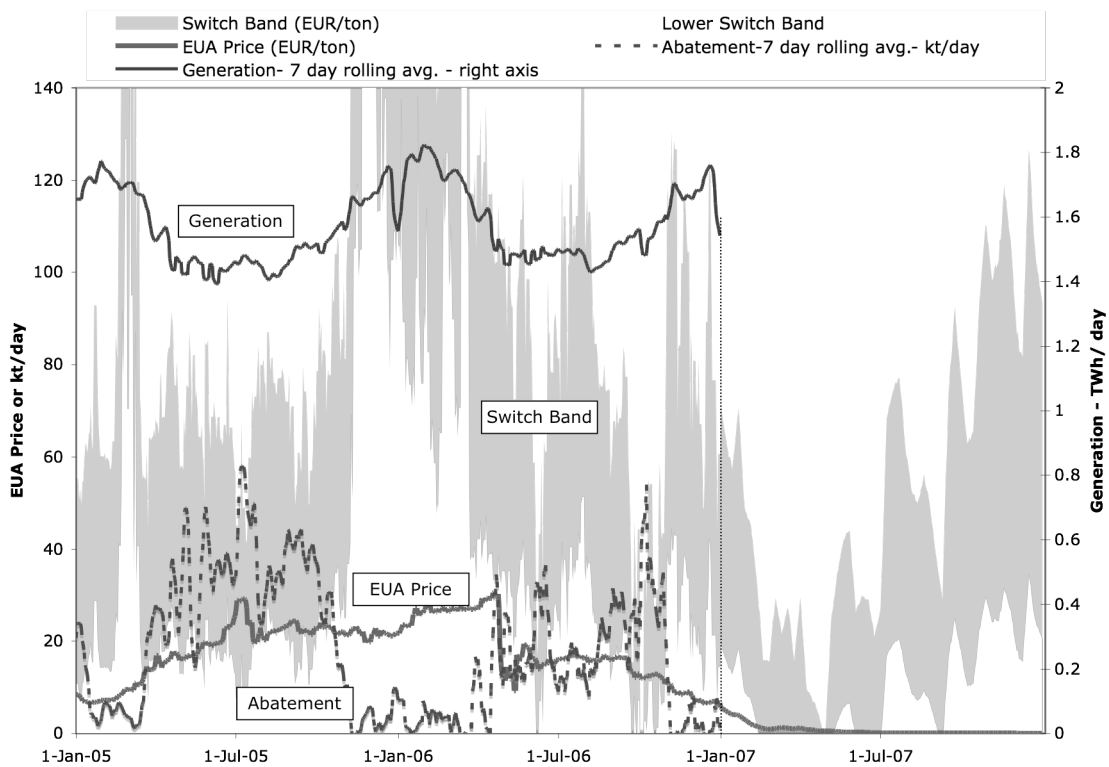
This part of the analysis relies on a simulation model, “E-simulate,” that was originally developed at the University of Leuven, Belgium and that has been subsequently calibrated to fit historical data from 2003 and 2004.¹ E-simulate is a cost minimization model that simulates European electricity generation dispatch on an hourly basis over an annual cycle at the power plant level. The entire system is organized as a set of interconnected ‘zones’, each of which corresponds to specific country or group of countries, of which Germany is one. Transfers of electricity can occur among zones subject to the pre-specified limits on interconnection capabilities. The demand for electricity is specified by zone for each hour of the year and the model solves for the least cost dispatch of generation to meet electricity demand in all zones, given daily fuel prices. E-simulate operates as a linked hourly stacking model in which the dispatch of available generation is determined by power plant characteristics and fuel prices. By

¹ More detail on the model can be found at Voorspools (2004), Delarue, Voorspools and D’haeseleer (forthcoming), and Delarue, Ellerman and D’haeseleer, (2008).

adding a cost for CO₂ the stacking order is usually changed in favor of lower CO₂-emitting generation with consequent abatement for most levels of demand. The results reported below reflect the German zone only, although those results flow from running the entire model including interzonal transfers that involve Germany.

As explained more fully in Delarue, Ellerman, and D'haeseleer (2008), CO₂ abatement through fuel switching depends principally on two factors: the availability of natural-gas-fired capacity and the prices of coal and natural gas. For any given stock of generating capacity, the availability of lower emitting gas-fired capacity that could be substituted for higher emitting coal-fired generation will depend upon the hourly load, which varies by daily, weekly, and seasonal cycles, and fuel prices. For instance, if natural gas prices are very low relative to those of coal, all gas generation will be committed anyway and there will be little to no capability to reduce CO₂ emissions by fuel switching. Similarly, when fuel prices favor coal-fired generation over gas-fired generation, as is usually the case, the amount of gas-fired generation available for switching will depend on the hourly load. On peak hours, when demand is high, most of the gas-fired generating capacity will be already committed so that there will be less low-emissions capacity available for switching. The interplay of these factors and their effect on abatement is illustrated in Figure 8 which shows the effect of both load and fuel prices on abatement by the German power sector in response to the observed EUA price.

Figure 8: Summary of Abatement Drivers



Source: Model results, Bloomberg

Due to the lack of demand data for 2007 when this analysis was performed, generation and abatement are shown only for 2005 and 2006. Load is shown by the black line at the top labeled generation (right axis in terawatt-hours/day) and it displays a decided seasonal variation reflecting the winter-peaking characteristics of German power demand. The reddish, dashed line at the bottom shows daily abatement (left axis in 000 tons/day) due to fuel switching. As can readily be seen, there is a distinct seasonal pattern to abatement. There is more in the summer when there is less demand on the system and when more uncommitted gas-fired generation is available for switching.

The effect of the CO₂ or EUA price (green line to be read on left axis in euro per ton) also depends on fuel prices. The blue band reflects the distribution of the fuel switching points, which depend on power plant efficiencies and fuel prices. A switching point can be defined as the EUA price at which available unused gas-fired capacity would be substituted for coal-fired generation. For any given pair of coal- and gas-fired plants competing on the electricity grid there is a single point, but since there are many pairs and the generation efficiency and delivered fuel prices vary for all of the possible pairs, there is in fact a switching band or distribution of switching points. This distribution is defined on the low side by the substitution of the most efficient and lowest cost unused gas-fired capacity for the least efficient and highest cost coal-fired capacity in service and on the high side by the substitution of the least efficient and highest cost gas-fired units for the most efficient and lowest cost coal-fired unit. Thus, the further the EUA price penetrates into this range, the greater abatement will be, all else being equal.

This fuel price effect can be observed in comparing the abatement in the summer of 2005 with that in the summer of 2006. As shown in Figure 8, EUA prices were well within the fuel-switching band during the summer of 2005, in contrast to the summer of 2006 when EUA prices were frequently below the switching band. When summarized over the two years by quarters, the seasonal pattern of abatement and the influence of these other price factors can readily be seen.

Table 2. Estimate of abatement in the German power sector

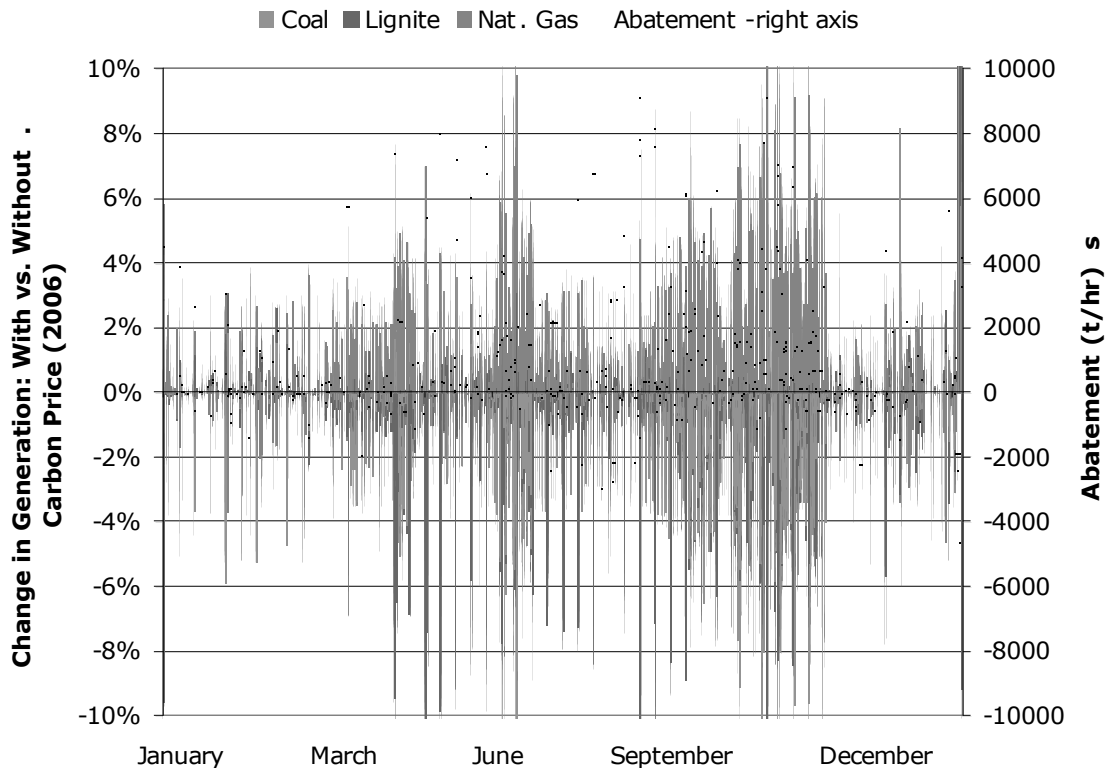
Mn tons	2005	2006	2007
Jan-Mar	0.85	0.34	0.1
Apr-Jun	2.98	1.61	0
Jul-Sep	3.61	1.81	0
Oct-Dec	0.87	1.05	0
Full year	8.31	4.81	0.1

Assuming little to no fuel switching in 2007, this bottom-up estimate indicates abatement of 13.2 million tons in the power sector alone for the three-year trial period, or about 1% of what emissions would have been in the ETS sectors in Germany (about 1.5 billion tons) and it can be taken as a lower bound for the reasons previously explained.

Further illustrations of power sector behavior in response to a CO₂ price

The extent and timing of fuel switching and the effect on abatement is illustrated more directly in Figure 9, which shows model results for 2005 alone.

Figure 9: Fuel switch between gas, coal and lignite and resulting abatement in 2006



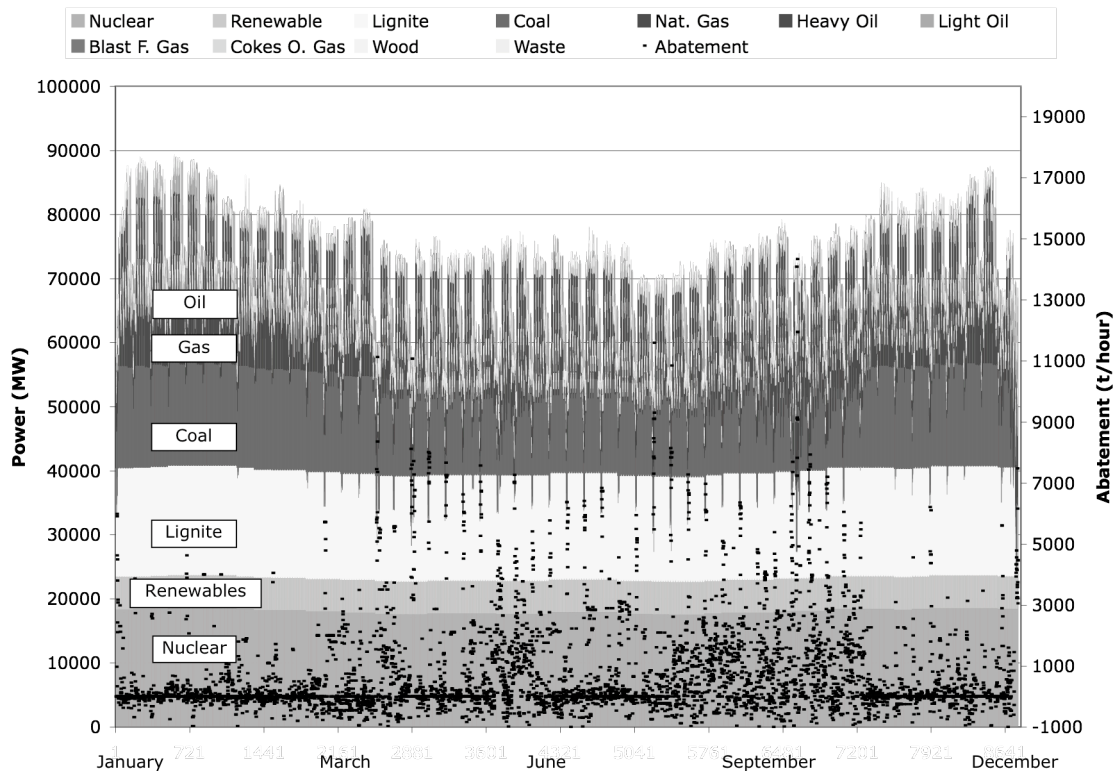
Source: Model results

Abatement is driven by gas displacing coal and lignite and the vertical lines show the percentage variations in generation from gas- and coal-fired power plants in response to actual EUA prices. Hourly abatement is shown by the black dots measured on the right axis in tons per hour. The same seasonal pattern is clearly shown here. Most fuel switching and abatement occur during the summer when more unused gas-fired capacity is available. But there is also a pronounced variation within each season reflecting daily and weekly cycles in load. Thus, there are hours throughout the year, including the summer, when relatively little switching and abatement occurs. These are chiefly the week-day peak hours when much of the gas-fired capacity is committed, regardless of fuel or CO₂ prices. Similarly, there are hours during the winter when switching and abatement occurs, chiefly during the week-ends and at night when the load is relatively lower. The concentration of abatement during the summer occurs because there are more hours with unused gas-fired capacity due to the lower load over-all during the summer months. As shown on the graph, when fuel switching occurs it varies between 2% and 12% at the EUA and fuel prices occurring in 2005.

Another interesting phenomenon in Figure 9 is the small amount of negative abatement due to reverse fuel switching that reflects the complexity and heterogeneity of any real electricity network. Plants vary in their ability to be shut-down or turned back so that associated ramping and turn-down costs are included in the cost-minimization algorithm of E-Simulate. These hours of reverse abatement are not frequent, but they do occur and they must be taken into account in any evaluation of abatement in such complex systems.

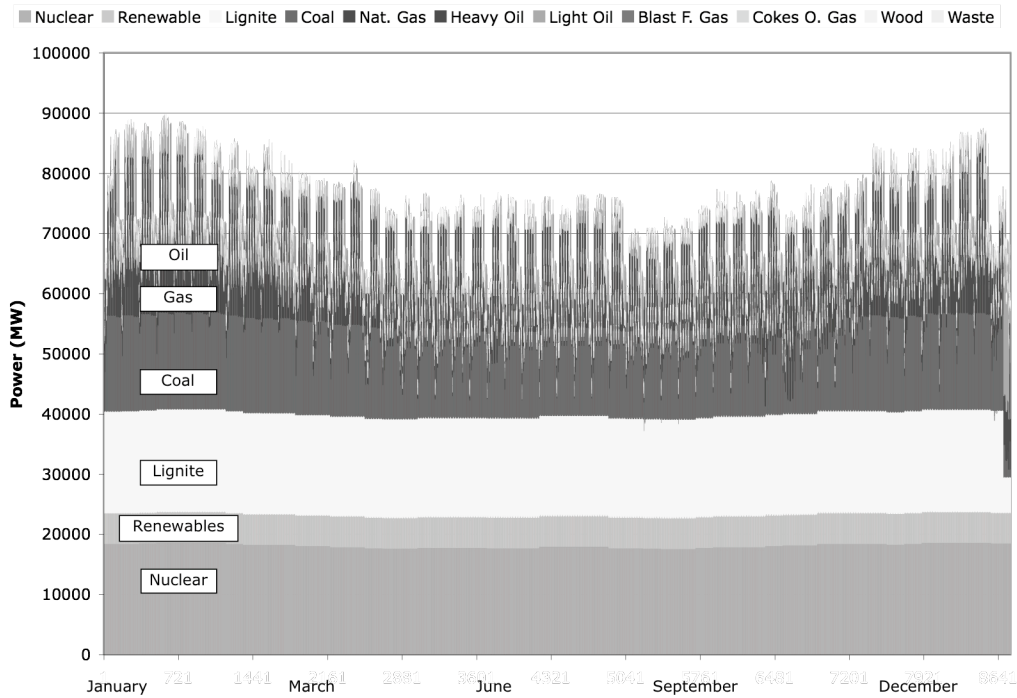
Figures 10a and 10b below provide a comparison of dispatch in the Germany electricity system in 2006 when there is no CO₂ price (10b) and when the actual CO₂ price (10a) are simulated. Figure 10a also shows hourly abatement. The picture that emerges from the comparison is a clear one. There are perceptible changes but the change is not as great as hoped or feared by various parties. With the observed CO₂ price, natural gas fired generation penetrated more deeply into the maroon, hard coal band and hard coal displaced some lignite (yellow band) mostly on week-ends during the summer when the highest abatement tends to be observed. What hasn't changed is that lignite and hard coal still provide an important part of base-load power and natural gas and oil fired units still provide the peaking capacity regardless of season.

Figure 10a: Model Results of Abatement and Load with a CO₂ price



Source: Model results

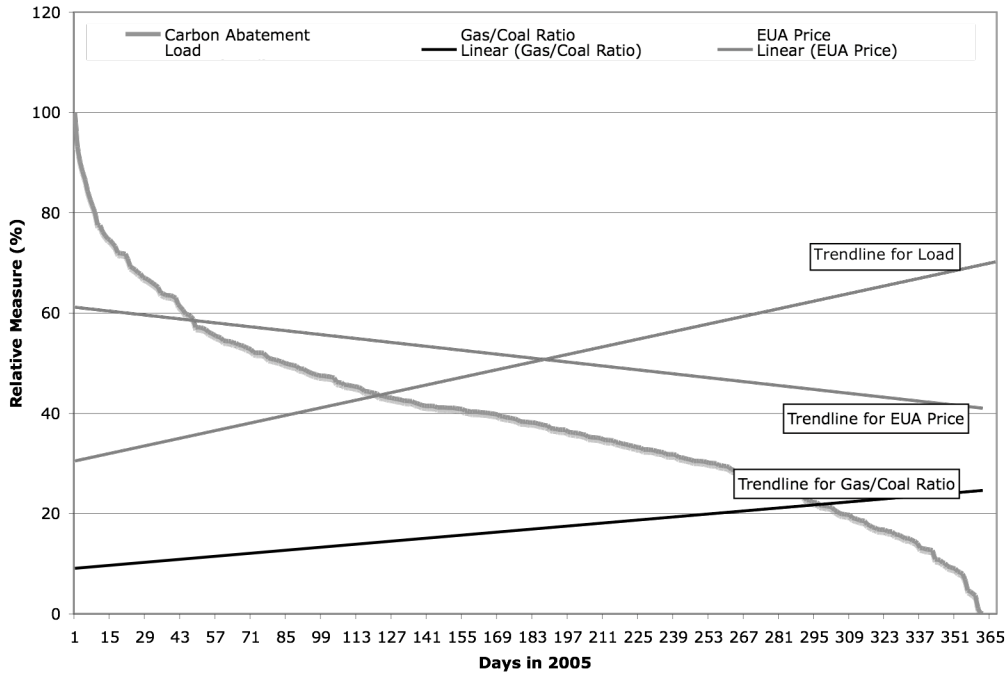
Figure 11b: Model Results of Abatement and Load without a CO₂ price



Source: Model results

The influence of load, fuel and CO₂ prices on abatement in the German power sector can be summarized as in Figure 11 below.

Figure 12: Days in 2005 ordered from high to low abatement



Source: Model results, Bloomberg

The figure aggregates the hourly abatement and generation data points into daily values to correspond to EUA and fuel price data. Then these daily values are ordered from highest to lowest abatement and expressed as a relative measure from 100 for the day with the greatest abatement to 0 for the day with the least abatement. Linear trend lines are added for easier analysis. High abatement tends to coincide at low loads when the system offers the most flexibility for fuel switching, lower gas/coal ratios the switching band is low, as well as high EUA prices so that the EUA price is most likely to fall within the fuel switch band. As load and natural gas prices increase relative to coal, and as EUA prices decline, abatement diminishes. As the slopes of the trend lines show, load has more effect than the price factors, and the gas/coal price ratio is as important as the EUA price in determining abatement.

Summary and Conclusions

The estimates of abatement provided here compare well with the estimates for the EU as a whole that have been provided by Ellerman and Buchner (2008, p. 34) of between 50 and 100 million tons, or of 2.5% to 5%, for each of 2005 and 2006. The similar top-down estimate for Germany that is developed in this paper tends to the upper end of this range on a percentage basis; however, they also clearly include other factors, particularly in 2007, which cannot be attributed to the EU ETS.

Minimum estimates can be provided by realistic bottom-up simulations of the power sector alone. The calibrated EU-wide simulation that is reported more extensively in Delarue, Ellerman and D'haeseleer (2008, p. 29), and replicated here, provides an estimate of 13 million tons for Germany (and 53 million tons for the EU as a whole) for the years 2005 and 2006 combined. These minimum estimates are approximately 1.3% of both German and EU-wide emissions on the unlikely assumption that the only abatement in response to the CO₂ price was in the power sector and in that sector only by fuel switching. The exact number or percentage is not as important as the evidence that there was some effect, although it was modest in keeping with the emission reduction ambitions of the trial period of the EU ETS.

The results presented in this paper should be considered “work in progress”. Future work on this paper will include a comparison of the model data with actual data and a careful reconsideration of the efficiency factors used for the German lignite and coal fleet. Furthermore, the inclusion of local commodity prices and long-term gas contracts would be desirable. Updates to this paper will be published as they become available.

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Appendix: Data used in figures and calculations

Raw Data:	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Phase I Total (2005-2007)
GDP- entire German economy- 2000 prices- bn Euros	1719.5	1760.6	1799.7	1785.3	1832.7	1867.4	1886	1920	1959	1998.4	2062.5	2088.1	2088.1	2083.5	2105.6	2122.1	2183.0	2237.2	
Gross value added- all industry including power- 2000 prices- bn Euros	557.9	554.25	519.6	536.28	530.83	517.86	530.27	532.85	537.18	561.55	561.16	551.3	551.3	548.9	567.5	569.3	599.3	627.4	
Gross value added- industry ex construction and power- 2000 prices- bn Euros	416.02	406.44	373.72	385.56	382.11	374.1	390.51	395.23	398.94	425.99	433.15	424.3	424.3	427.4	442.6	448.9	475.0	504.3	
Gross value added- utilities only- 2000 prices- bn Euros	34.102	33.682	33.592	32.592	34.486	36.513	35.863	36.386	36.041	36.7	34.7	36.6	36.6	36.1	42.2	42.2	42.6	41.2	
German total power generation (TWh)	549.9	540.21	538.16	527.12	528.47	536.82	552.62	552.31	557.3	556.25	576.5	586.4	586.7	606.7	615.3	620.6	636.8	632.0	
German fossil power generation (TWh)	358.4	359.2	342.6	336.6	336.9	339.9	350.7	340.32	350.3	337.17	346.5	354.8	357.6	375.9	370.5	370.7	372.8	378.0	
Primary Energy use- entire German economy (EJ)	14.905	14.61	14.319	14.309	14.185	14.269	14.746	14.614	14.521	14.323	14.402	14.679	14.427	14.46	14.656	14.469	14.565	13.842	
Emissions: German EU-ETS installations (DEHS)- mn tonnes	470.7	530.2	502.82	486.36	489.35	480.57	482.86	464.69	467.81	453.26	471.8	473.4	478.3	488.4	487.4	473.7	477.3	487.0	1438.0
Emissions: Electricity sector (Mission Climat estimate)- mn tonnes																290.6	291.6	299.8	882.0
CRF emissions from subsectors matching EU-ETS	445.87	502.22	476.29	460.69	463.53	455.21	457.38	440.17	443.13	429.34	445.87	448.11	448.75	464.85	465.32	456.15			
Representative Calculation #1:																			
Observed Emissions (all EU-ETS sectors)	471.8	473.4	473.4	473.4	473.4	473.4	473.4	473.4	473.4	473.4	473.4	473.4	473.4	473.4	473.4	473.7	477.3	487.0	1438.0
Observed Activity Index (GVA industry and power)	561.6	561.2	561.2	561.2	561.2	561.2	561.2	561.2	561.2	561.2	561.2	561.2	561.2	561.2	561.2	569.3	599.3	627.4	
Calculated Emissions Intensity (emissions/activity index)	0.8402	0.8436	0.8436	0.8436	0.8436	0.8436	0.8436	0.8436	0.8436	0.8436	0.8436	0.8436	0.8436	0.8436	0.8436	0.8321	0.7964	0.7762	
Intensity Growth Trajectory 2000-2004 extrapolated into Phase I																0.8636	0.8683	0.8731	
Emissions Counterfactual = Emissions using extrapolated intensity and observed activity index																491.64	520.44	547.82	
Abatement = Difference between observed and counterfactual emissions																17.9	43.1	60.8	121.9
2000-2004 Growth Rate:																			
Representative Calculation #2:																			
Observed Emissions (power sector- Mission Climat estimate)	289.2	290.2	293.2	293.2	293.2	293.2	293.2	293.2	293.2	293.2	293.2	293.2	293.2	293.2	293.2	290.6	291.6	299.8	882.0
Observed Activity Index (GDP)	2062.5	2088.1	2088.1	2088.1	2088.1	2088.1	2088.1	2088.1	2088.1	2088.1	2088.1	2088.1	2088.1	2083.5	2105.6	2122.1	2183.0	2237.2	
Calculated Emissions Intensity (emissions/activity index)	0.1402	0.139	0.1404	0.1404	0.1404	0.1404	0.1404	0.1404	0.1404	0.1404	0.1404	0.1404	0.1404	0.1404	0.1404	0.1369	0.1336	0.1334	
Intensity Growth Trajectory 2000-2004 extrapolated into Phase I																0.1427	0.1435	0.1443	
Emissions Counterfactual = Emissions using extrapolated intensity and observed activity index																302.78	313.17	322.73	
Abatement = Difference between observed and counterfactual emissions																12.2	21.6	22.9	56.7
2000-2004 Growth Rate:																			
Abatement for all EU-ETS sectors using counterfactual based on GVA intensities																17.9	43.1	60.8	121.9
Abatement for all EU-ETS sectors using counterfactual based on GDP intensities																19.0	31.0	35.5	85.5
Abatement for power sector using counterfactual based on power generation intensities																12.5	21.1	12.2	45.7
Abatement for power sector using counterfactual based on GDP intensities																12.2	21.6	22.9	56.7