Air Transport in the European Union Emissions Trading Scheme

Thematic Area: Economics

Final Report

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Executive Summary

Context and Aim

Despite the relatively small current contribution (3.2% in 2004 – EEA, 2007) to European CO_2 emissions, the aviation sector is argued to be in need of additional mitigation action. This is due to the rapid expansion and estimated future growth[1] of traffic and related greenhouse gas emissions of the sector caused by liberalisation of the air transport market, the rapid spread of the low-fare business models and the current mature aircraft technology that limits easy technical fixes for CO_2 savings. Integrating aviation into the European Union Emissions Trading Scheme (EU ETS) from 2012 is the first major international policy measure to control this growth. Emissions trading is argued to be the best way of tackling the aviation industry's greenhouse gas (GHG) emissions (DfT, 2003). The EU ETS will set a cap on CO_2 emissions from the aviation sector by allocating certain amount CO_2 allowances for each of the airlines. These airlines those emissions exceed their allocation (cap) can either buy extra allowances from the European carbon market or reduce their emissions. These airlines that will emit less CO_2 than their allocation can sell the excess allowances on the market.

The aim of this study is to explore the possible impacts on the aviation industry and general economic activity of including the aviation sector in the EU ETS. The starting point was the EU Commission proposal for including aviation in the EU ETS, from 2011-2012. The proposal involved into European Union Directive 2008/101/EC (2009) after the vote of the EU Parliament in July 2008. This study uses latest available information about the scheme design (section 2). This study examines possible impacts on the aviation industry (demand), on CO_2 emissions, and macroeconomic activity (GDP) in the EU. The study also explores how the 2008 fuel price increase impacted the air transport sector and how this compares with the carbon price impacts.

Approach adopted and key assumption

This is the first study to assess inclusion of the air transport sector in the EU ETS using and integrated whole system approach for European Economy. The Energy-Environment-Economy Model for Europe (E3ME – for a detailed description of E3ME see Annex 1 below and Cambridge Econometrics (2008)) is used in this study. E3ME is a hybrid post-Keynesian macroeconomic dynamic simulation model. It is designed to assess short and medium run (up to 2020) GHG mitigation policies, including emissions trading schemes (see for example: Köhler et al. 2008; SEC 2008; Barker et al. 2007). The model is

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[1] The annual growth of revenue tonne kilometres is estimated to be 4-5% – DfT, 2003; Boeing, 2008.

a combination of time-series econometric relationships (estimations are based on data covering the period 1970-2004) and cross-section input-output relationships. It can simulate air transport in interaction with 41 other industrial sectors in a particular region (an EU member state) and in a group of regions (the EU).

In this study, allowances are allocated to the air transport industry at no cost or are auctioned depending on the scenario. It is assumed that the cost of auctioned and purchased carbon allowances from the market (as well as the opportunity costs of freely allocated allowances) is fully passed on to consumers by increasing prices for air transport. In the model, these costs are added to fuel costs: increasing fuel costs impacts the industry's fuel demand through an econometric fuel demand equation. CO_2 emissions are estimated from fuel use by using a conversion factor. The opportunity costs of freely allocated allowances increase industry profits, and therefore also investments in the industry that help the industry to invest in the carbon reduction measures. The costs of auctioned allowances increase governments' expenditures and is equally distributed between four expenditure categories (e.g. defence, education, health, other). The use of credits from the Kyoto Clean Development Mechanism (CERs) is limited to a maximum 15% per a trading year. Table S.1 gives an overview of the scenarios used.

Scenario	**Allocation**	**CERs 15%**
A	15% auctioning from 2012 to 2030, remainder free allocation	Yes
B	15% in 2012, from 2013 20% auctioning with phasing out by 2020, remainder free allocation	Yes
A1	15% auctioning from 2012 to 2030, remainder free allocation	No
B1	15% in 2012, from 2013 20% auctioning with phasing out by 2020, remainder free allocation	No
MIN	100% free allocation	Yes

Table S.1. Carbon trading scenarios used in current study

For the current study, three allowance price scenarios were used:

1. a low price scenario of €5 (2008 prices) per tonne of CO_2,
2. a medium price scenario of €20 per tonne of CO_2, and
3. a high price scenario of €40 per tonne of CO_2.

For each of the allowance prices, the scenarios (see Table 1) are compared to the REF scenario that does not restrict aviation emissions. This allows exploration of the impacts of inclusion of the aviation sector under three different allowance price scenarios of the EU ETS.

Summary of findings

The study finds that the aviation sector is expected to purchase excess allowances from the other sectors covered by the EU ETS. This result is robust to different allowance prices (from €5 to €40 per tonne of CO_2, year 2008 prices). The inclusion of the aviation sector, as it is proposed by the European Parliament, may result in small reductions in demand for airline services (about 1% by an allowance price of €40) in 2020. The study finds that the inclusion of the sector may result in reductions in emissions by air transport – up to 7.5% in CO_2 (by an allowance price of €40) compared with no action baseline in 2020.

The current study also analyses impacts on real GDP by 2020. The impacts on GDP were negligible and suggested that including aviation in the EU ETS will not affect the EU's competitiveness by reducing economic growth in the region[2]. This finding does not take into account the impact of market shares shifting to non-EU carriers if they are allowed to avoid compliance. A comparison of impacts on Member States shows slightly larger impacts on old Member States than new Member States, contrary to previous literature. This result comes from the larger share that the aviation sector makes up in old Member states. In this study all auctioning revenues were used to increase Member States governments' expenditures. Recycling of these revenues by reducing regional employers' contributions to social security may alter this conclusion.

Usage of credits from the Kyoto Protocol's Clean Development Mechanisms helps aviation to reduce compliance costs, but gives less reduction in CO_2 emissions and a slightly negative impact on GDP.

Higher levels of auctioning will impose more real costs on the industry and, because 100% cost pass through was assumed, it might not impact the industry level CO_2 reduction. However, the study confirms that how the auctioning revenues are used is extremely important - by allocating revenues into non-ETS sectors, slight increases in carbon emissions at the EU level might be possible.

The study also used three oil price scenarios to assess the impacts of the 2008 oil price shock on the air transport industry, and found that the shock is comparable with the effect of including the industry in EU ETS with a carbon allowance price of €40 per tonne of CO_2. The study also suggests the macroeconomic impacts of high oil prices will be more severe than these from a carbon trading scheme and may result in losses of 3% annual GDP in the EU in 2020. This is caused by higher payments for imported oil.

The reasons for not exploring greater impacts are because of the low price elasticities of demand and relative small scale of the industry. Airlines passing on to consumers the cost of purchased allowances, as well as the cost of freely allocated allowances (opportunity costs), will charge higher fares and face lower demand. However, empirical evidence from the effects of the

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[2] The study uses a reference case that does not allow for the effects of the global economic recession.

kerosene price increases over the past five years and the Air Passenger Duty imposed in the UK in January 2007 does not show significant effects on revenue tonne kilometres (RTK) flown (ICAOData, 2008) suggesting low price elasticities of demand. It seems likely that increases in airfares resulting from airlines purchasing allowances will be modest and not sufficient to cause significant reductions in demand.

The amount of allowances needed by aviation will also be small (up to 2.5%) compared with the size of the trading scheme. In addition, the aviation industry counts for a relatively small share of GDP in most of the EU Member States. Inclusion of air transport emissions to the EU ETS, as it was proposed by European Parliament in July 2008, will not significantly affect the EU economy as a whole and the economies of separate EU Member States.

Nevertheless, there exists some potential for aviation to reduce its emissions at a cost lower than that of purchasing allowances (Stratus, 2005; SEC, 2006; EBPDB, 2007; Morris et al, 2008). For instance, this can be done by reducing the amount of excess fuel and/or water, as well as baggage carried on board during flight. The prospect of buying allowances may well provoke the airlines into investigating and implementing other such options, which is indeed one of the objectives of the scheme in the first place.

To summarise, inclusion of aviation in the EU ETS is not expected to impact growth in the air transport sector significantly in the EU and its Member States, and seems unlikely to reduce carbon emissions substantially, either at industry or EU level. However, the concept of emissions trading is to use the market to implement emission reductions at the lowest cost. Industries where emissions abatement is expensive ‘fund’ abatement in industries where it is cheaper. In effect, through engagement in the EU ETS, the aviation industry will ‘pay’ for emission reductions, for example in the power sector.

Gaps and uncertainties – areas of further research

The main uncertainty related to this study stems from the fact that the rules for the third trading period (2013-2020) have not been finalized. This uncertainty is closely related to Post-Kyoto policies for climate change that are still to be negotiated under UNFCCC umbrella.

The study results, however, depends crucially on the equal applicability of the emission trading scheme to all airlines that operate in the EU. If non-EU airlines were able to avoid the emission trading scheme, EU based non-EU airlines would be able to gain market share. Thus, instead of reallocating economic activity to non-aviation sectors, economic activity would be redirected to non-EU nations. There may also be leakage opportunities for non-EU carriers if they were included in the scheme, e.g. flying into a destination close to the EU instead of flying into the EU. The magnitude of potential leakage under the current directive has yet to be estimated.

Using CDM credits by the air transport sector was explored under two levels - 0% and 15%. Studying a wider range of CDM credit scenarios combined with possible European carbon reduction targets for post-Kyoto period (from 2013) could help to gain more insight to the relevance of the CDM credits for aviation and the EU economy. Similarly, it could be beneficial to explore impacts for various ways of spending auctioning revenues.

The main disadvantage of using E3ME as it was done in this study for assessing policy impacts on a particular industry is that it analyses the industry at an aggregate level (unless the model incorporates an industry-specific sub-model, such as the energy technology sub-model). E3ME does not have a transport sub-model, though one is under development. Therefore, impacts on different business models, flight routes and technologies inside the air transport sector cannot be investigated. There are emerging studies in this area (Mendes and Santos, 2008; Scheelhaase and Grimme, 2007; Morrell, 2007). The air transport industry may well benefit of further business model based and technology based studies, especially if they do not ignore interactions with wider economic activity. Therefore using a hybrid model that combines top-down macroeconomic modelling with a bottom-up industry specific sub-model could be preferable.

Potential for informing policy

The main importance of the study has been to examine the impacts of carbon trading on the aviation industry considered within the context of the whole economy. This reveals the effects of the feedbacks between all of the sectors, of which aviation is only a part. It shows us that this trading scheme basically creates a shift in the economy, where the sectors that can reduce carbon emissions easiest do so first. Overall emissions targets can be met while allowing the economic changes to be driven by free choices, albeit slightly weighted by the carbon emissions involved. The model will also allow test runs for different possible rules and regulations from 2013 – 2020, thus providing some advice and guidance for policy makers.

1 Introduction

Aircraft emissions contribute to climate change by increasing the concentrations of greenhouse gases (GHGs) in the atmosphere (IPCC, 1999). Carbon dioxide emissions from international aviation comprised 3.2 % of EU inventories in 2004 (EEA, 2007). Growth in CO_2 emissions from international aviation in EU countries showed 85% growth from 1990 to 2004 (EEA, 2007). In addition, aircraft emit nitrous oxides, sulphur dioxide, soot and water vapour. Less well understood warming effects attributed to aircraft emissions include the formation of condensation trails (contrails) and cirrus clouds (IPCC, 1999).

There are currently no binding policies in place to tackle the climate change issues related to international air transport. For example, the Kyoto Protocol (1997) targets do not include aviation emissions from international flights. The EU has decided to tackle the problem unilaterally, and in December 2006 a proposal for including the aviation industry (all domestic and international flights) in the EU ETS was released and in July 2008 the European Parliament decided to include aviation to the scheme from 2012. Hence, the EU ETS will also cover the CO_2 emissions from the aviation industry that are currently not covered by the Kyoto Protocol.

A binding emission trading scheme (one with significant allowance price impacts) has the potential to reduce CO_2 emissions. This kind of scheme has the potential to induce behavioural changes in the short and medium term, and technological changes in the longer term, through the price signals it sends to the aviation industry via consumers.

Whether or not the inclusion of the aviation sector in the EU ETS has broader impacts on the EU's aviation industry depends on the scope of the final rules (e.g., does it apply to non-EU based companies?); the price impacts on airline tickets; and the extent to which non-covered carriers are able to gain market share.

The air transport industry is intimately connected with other sectors of the economy - models omitting these connections will be incomplete. For example, the feedbacks between the air transport industry and GDP (via other sectors, such as leisure) are not represented. This report studies the impacts of the proposed policy using an integrated multisectoral approach: The Energy-Environment-Economy Model for Europe (E3ME). E3ME is a multi sectoral model allowing the investigation of the air transport industry in interaction with other industries by taking two-way intersectoral feedbacks into account.

This study examines possible impacts on the aviation industry (demand), on CO_2 emissions, and macroeconomic activity (GDP) in the EU. It will not discuss legal aspects of aviation emission trading or impacts on other industries (e.g. tourism etc). The study also explores how the 2008 fuel price increase impacted the air transport sector and how this compares with the carbon price impacts.

2 European Emissions Trading Scheme

In an emissions trading scheme (ETS), the aggregate amount of emissions by market participants is limited to, or capped at, a certain level. Allowances are issued corresponding to the cap, and the trading of these allowances in the market creates a price for a unit of emissions. An ETS encourages those with lower marginal abatement costs to abate and to sell their allowances to those with higher abatement costs. This approach is especially suitable for uniformly distributed greenhouse gases, such as $CO_{2,}$ where the location of emission reductions does not matter.

The European Union ETS (EU ETS) is currently the world's largest ETS and the first ETS that crosses country borders. The EU ETS came into operation on 1 January 2005 and is the centrepiece of current European climate change policy. The EU ETS is currently in its second phase that runs from 2008 – 2012. The EU ETS includes CO_2 emissions from energy intensive industries in the European Union (Directive 2003/87/EC, 2003). In December 2006, the EC released a proposal on including the airline industry in the EU ETS from 2011[3] (Proposal for amending Directive 2003/87/EC, 2006). Under this proposal, the airline industry would be the first transport sector to be included in the EU ETS.

The EC Proposal foresees the following important design elements:

1. All airlines operating within the EU will be included in the EU ETS as trading entities. This also includes the third country airlines landing at and departing from the EU airports.
2. An EU-wide emissions cap will be implemented based on historical emissions (equal to the mean average of the annual emissions in the calendar years 2004-2006 from all aircraft taking off or landing in the EU) in order to stabilise CO_2 emissions from the aviation sector at the 2005 level.
3. Allowances will be distributed to individual airlines in proportion to tonne-kilometres flown in the calendar year ending 24 months before the start of the first trading period for the airline industry (the benchmark period or reference year). The number of allowances allocated to each aircraft operator will be equal to the benchmark multiplied by the tonne-kilometres flown in the benchmark period. The benchmark will be calculated by dividing the EU wide cap for air

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[3] All domestic flights from 2011 and all international flights from 2012.

transport by the total tonne-kilometres flown over the benchmark period by all airlines included in the EU ETS.

4. The allocation methodology is to be similar across all Member States. A certain percentage of allowances will be granted for free, and the rest will be auctioned.
5. Certified Emissions Reductions (CERs[4]) and Emission Reduction Units (ERUs[5]) from two Kyoto flexible mechanisms (i.e. Clean Development Mechanism and Joint Implementation respectively) may be used up to a limit to be set by the EC.
6. An open trading system is proposed - i.e. the airline sector can trade with all other sectors covered by the EU ETS. The only restriction will be that airlines cannot sell their allowances to the trading sectors other than the air transport sector itself. This is because the allowances that are issued for airlines under the EU ETS are not backed with the Kyoto allowances nor included to the Kyoto targets.
7. New entrants will purchase allowances via the market or through an auction.
8. The inclusion of airlines will be irrespective of nationality and business model.

Under the current proposal, the costs of inclusion will differ between airlines as fuel consumption, per flight by route, differs between airlines according to the fuel efficiency of the aircraft used, operational practices and the level of passengers and freight carried (SEC, 2006). More efficient airlines will face lower costs than less efficient airlines.

On 9 July 2008 the European Parliament had a final vote on inclusion of aviation in the EU ETS. The main amendments to the original proposal described above are (Directive 2008/101/EC, 2009):

1. In 2012 the number of carbon allowances allocated to airlines will be capped at 97% of average greenhouse gases emitted in 2004-2006. This cap would then be lowered to 95% for 2013,
2. The first benchmark period (reference year) will be 2010, thereafter the calendar year ending 24 months before the start of the period to which the auction relates
3. 15% of the allowances will be auctioned in 2012,

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[4] CER (Certified Emission Reduction Unit) is equal to 1 tonne (metric ton) of CO2-equivalent emissions reduced or sequestered through a Clean Development Mechanism project, calculated using Global Warming Potentials (IPCC, 2007).

[5] ERU (Emissions Reduction Unit) is equal to 1 tonne (metric ton) of carbon dioxide emissions reduced or sequestered arising from a Joint Implementation (defined in Article 6 of the Kyoto Protocol) project calculated using Global Warming Potential (IPCC, 2007).

4. Airlines are allowed to use CERs and ERUs up to 15% of their EU ETS allocation in 2012
5. Special reserve of allowances (3% of total quantity of allowances) will be established for new entrants and fast growing airlines.

These figures could be subject to change as part of the ongoing review of the EU's general Emissions Trading Scheme for the third phase 2013-2020 (for more discussion - see SEC (2008)).

It should also be stressed that including aviation in the EU ETS will only be a part of a comprehensive package of measures to tackle the climate change impact of aviation. The other measures proposed by European Community include operational and technological measures (Directive 2008/101/EC, 2009).

3 Methodology

The Energy-Environment-Economy Model for Europe (E3ME – for a detailed description of E3ME see Annex 1 below and Cambridge Econometrics (2008)) is used in this study. E3ME is a hybrid post-Keynesian macroeconomic dynamic simulation model. It is designed to assess short and medium run (up to 2020) GHG mitigation policies, including emissions trading schemes (see for example: Köhler et al. 2008; SEC 2008; Barker et al. 2007). The model is a combination of time-series econometric relationships (estimations are based on data covering the period 1970-2004) and cross-section input-output relationships. It can simulate air transport in interaction with 41 other industrial sectors in a particular region (an EU member state) and in a group of regions (the EU).

This kind of model structure allows two-way feedbacks between sectors in response to a particular policy imposed on one industry, or a group of industries. For example, if demand for air transport decreases, then the money that is not spent on flying is spent elsewhere. This feeds back to air transport through increased demand for air transport in these sectors, and this partly offsets the initial decrease in demand.

This integrated approach is distinguished from the spreadsheet and multi-model approaches. For example, Ernst and Young (2007) and Frontier Economics (2006) use static spreadsheet models that do not incorporate influences from other changes in economy (e.g. changes in incomes, developments in other transport sectors). Similarly, static spreadsheet models are also used to estimate the impacts of the EU ETS on selected passenger airlines (Scheelhaase and Grimme, 2007) and to observe the effects of different allocation methods (Morrell, 2007).

CE Delft (2005, 2007) and SEC (2006) use a multi-model approach. In principle, linked models can be estimated and solved consistently for different economic sectors and nations. However, in practice this often proves difficult, and considerable uncertainties are introduced in the linking. Even if the consistency problem in linkage can be solved by successive iterative solutions of the component models, there remains a more basic limitation with the multi-model approach in that they do not readily incorporate macroeconomic feedbacks into the detailed sectoral models. Normally these systems are first solved at the macroeconomic level, and then the results for the macroeconomic variables are disaggregated by an industry model. However, if the policy is directed at the detailed industry level (say, a tax on the carbon content of energy use), it is very difficult (without substantial intervention by the model operator) to ensure that the implicit results for macroeconomic variables from the industry model are consistent with the explicit results from the macro model (Cambridge Econometrics, 2008). Therefore, it is desirable to use a single model -- or modelling system -- to estimate the impacts of including aviation in the EU ETS, as is the case in this study.

E3ME has the following advantages:

1. Model disaggregation: The detailed nature of the model allows the representation of fairly complex scenarios, especially those that are differentiated according to sector or country. Similarly, the specific impact of any policy measure can be represented in a detailed way.
2. Data driven: The model is driven by detailed historical data combined with state-of-the-art econometric forecasting techniques. This data-driven approach makes it better able to represent and forecast performance in the short to medium run.
3. It provides information that allows for dynamic responses to changes in policy linkages: E3ME is a hybrid model. The ability to model interactions between the economy, energy demand/supply and environmental emissions provides an advantage over models that may either ignore the interaction completely or only assume a one-way causation. For example, the EU ETS includes a cap on CO_2 emissions: the model can be used to solve different CO_2 allowance prices, allowing for effects on prices and demand, as well as on macroeconomic variables.

The main disadvantage of using E3ME for assessing policy impacts on a particular industry is that it analyses the industry at an aggregate level (unless the model incorporates an industry-specific submodel, such as the energy technology submodel). E3ME does not have a transport submodel, though one is under development. Therefore, impacts on different business models and technologies inside the air transport sector cannot be investigated.

4 Modelling aviation in the EU ETS and assumptions

E3ME incorporates a special subroutine to assess the impacts of an emission trading scheme. Carbon dioxide (as the tradable gas under the EU ETS) is the only GHG included in the subroutine. For this study, the emissions trading subroutine was revised and developed, and the air transport sector was added as one of the trading sectors in the sub-model. A specific code that allows an assessment of the impact of use of CDM credits (CERs) was also written and added to the subroutine. Exogenous carbon allowance and CDM credit prices and the industry specific allowance allocations were included in the model through specific input files – scenario files. The scenario file structure was also amended to allow the inclusion of air transport at different time points and to make use of CDM credits and to allow for exogenous price for these credits.

In this study, allowances are allocated to the air transport industry at no cost or are auctioned depending on the scenario. It is assumed that the cost of auctioned and purchased carbon allowances from the market (as well as the opportunity costs of freely allocated allowances) is fully passed on to consumers by increasing prices for air transport. In the model, these costs are added to fuel costs: increasing fuel costs impacts the industry's fuel demand through an econometric fuel demand equation. CO_2 emissions are estimated from fuel use by using a conversion factor. The opportunity costs of freely allocated allowances increase industry profits, and therefore also investments in the industry. The costs of auctioned allowances increase governments' expenditures and is equally distributed between four expenditure categories (e.g. defence, education, health, other).

Based on the information in section 2, we study the following emissions trading scenarios:

Scenario	**Allocation**	**CERs 15%**
A	15% auctioning from 2012 to 2030, remainder free allocation	Yes
B	15% in 2012, from 2013 20% auctioning with phasing out by 2020, remainder free allocation	Yes
A1	15% auctioning from 2012 to 2030, remainder free allocation	No
B1	15% in 2012, from 2013 20% auctioning with phasing out by 2020, remainder free allocation	No
MIN	100% free allocation	Yes

Table 1. Carbon trading scenarios used in current study

These scenarios (Table 1) are compared with a reference scenario (REF) that is the same as the A (Figure 1) scenario without the air transport sector in the EU ETS. Scenarios A and B (see figures 1 and 2) differ according to the levels of auctioning. Reference scenario A has a fixed auctioning level of 15% as it stands in the current legislation. Reference scenario B follows the proposal for the trading phase 3, and has 15% of auctioning in 2012 and 20% in 2013, which will thereafter increase up to 100% in 2020. Scenarios REF, A and B assume that CERs[6] are used in amounts that equal the maximum of 15% of the allowance allocation. Comparing scenarios A and B and MIN (no auctioning) enables a study of the impacts of auctioning.

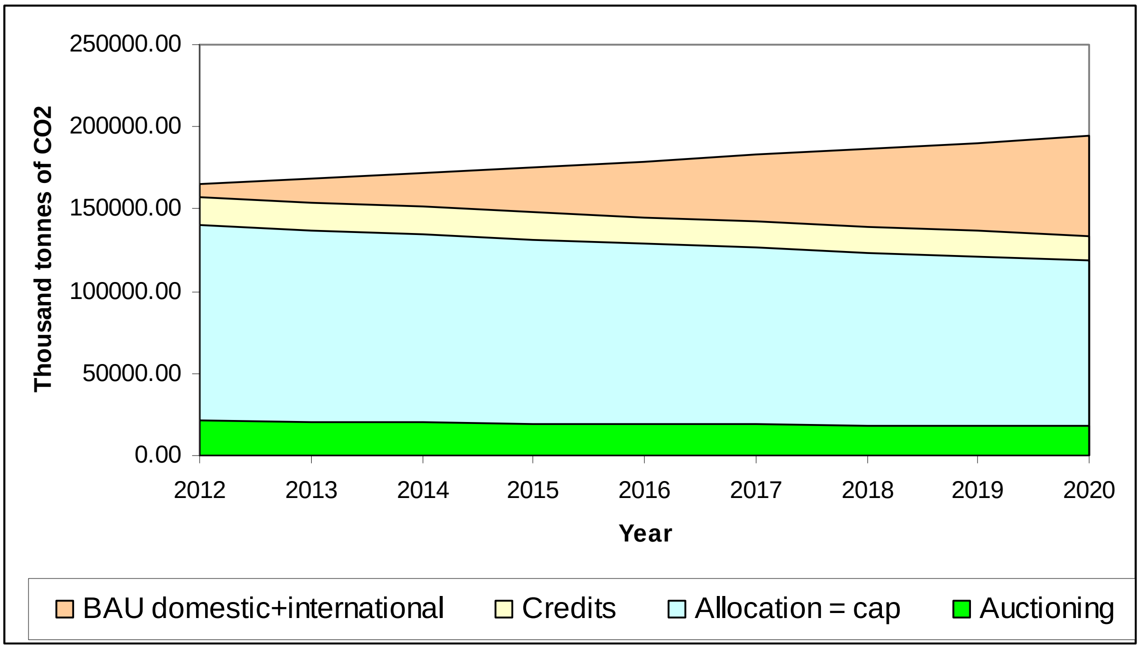

Figure 1. Scenario A

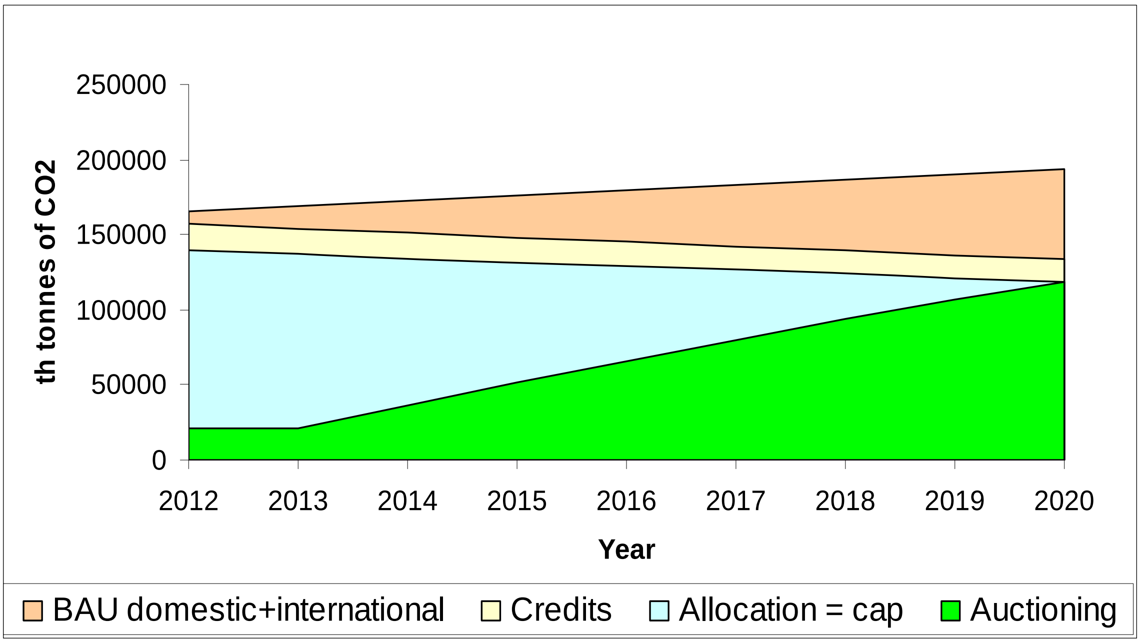

Figure 2. Scenario B

In the model, CO_2 emissions for air transport are capped at the 97% and 95% levels of the years 2004-2006 for the first and second trading year respectively, and thereafter diminishing to 21% below this level within the trading period 2014-2020 (consistent with the proposed legislation - COM,

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[6] To simplify modelling, we have assumed that ERUs from the new EU Member States are not used.

2008). All other trading sectors emissions are capped according to their National Allocation Plans for the second trading period (2008-2012), thereafter gradually diminishing to 21% below the 2005 level from 2013 to 2020. It is assumed that both international and domestic air transport are included in the EU ETS from 2012. The use of credits from two other Kyoto flexible mechanisms (maximum 15% per a trading year) is also studied in order to explore the importance of the inclusion of these credits. Scenarios A1 and B1 are without use of CERs. Comparing scenarios A and B with scenarios A1 and B1 allows exploration of the impacts of incorporating these credits in the trading scheme. However assuming maximum 15% of incorporation of CDM credits per year might not be consistent with the future policy scenario.

For the current study, three allowance price scenarios were used:

1. a low price scenario of €5 (2008 prices) per tonne of CO_2,
2. a medium price scenario of €20 per tonne of CO_2, and
3. a high price scenario of €40 per tonne of CO_2.

The medium price scenario was chosen because it reflects the current (September 2008) allowance price level under the EU ETS. The low and high price scenarios were chosen to try to take into account the uncertainties related to carbon price. For each of the allowance prices, the scenarios (see Table 1) are compared to the REF scenario that does not restrict aviation emissions. This allows exploration of the impacts of inclusion of the aviation sector under three different allowance price scenarios of the EU ETS. The results of policy designs are reported for 2020 as this is the anticipated end year of the third trading phase of the EU ETS.

5 Results: Scenario A

As Scenario A (see table 1) follows the current proposal of including air transport in the EU ETS, the following chapter focuses on the modelling results of this scenario.

5.1 Impacts on air transport sector

In E3ME, economic activity in the aviation sector is endogenous; aviation activity increases and decreases with economic growth and contraction, along with other factors. Since E3ME is a fully-integrated model, growth or decline in aviation activity contributes to growth or decline in overall economic output. Under the BAU scenario, aviation activity grows at an average annual rate of about 2.5% (exceeding 3% until 2015 and less thereafter) and incorporates about 1% fuel efficiency improvements per year. This number is conservative compared with other studies that assume average yearly growth rate of about 4% (see for example Bows et al, 2005 and CE Delft, 2005). While conservative, this rate is consistent with the lower end of the growth scenarios projected in SEC, 2006. The lower projected growth rate in aviation activity in the reference scenarios means that, all else equal, aviation emissions and demand for allowances will be smaller than if we had used a larger growth rate for aviation activity.

The structure of E3ME allows the researcher explore which sectors are buyers and which ones sellers of allowances under an emissions trading scheme. The model runs done for this study show that the air transport sector will be a buyer of allocated allowances for allowance prices of €40 to €5 per tonne. This result is consistent under all three price-scenarios from 2012 to 2020. This agrees with current literature that assumes marginal abatement costs for the aviation sector to be higher than those for other sectors covered by the EU ETS (SEC, 2006; Frontier Economics, 2006; CE Delft, 2005). Therefore, non-aviation sectors reduce their emissions and sell their allowances to the air transport sector. Under all the price scenarios, the power sector will be the major seller of the allowances.

A high price makes allowances less attractive, and therefore fewer allowances are purchased and airlines abate more themselves. A lower allowance price leads to more net purchases and less abatement activity by the air transport sector.

Impacts on economic activity

If the air transport sector buys allowances from the market to cover its excess demand for carbon allowances, then it faces extra costs. Increasing costs have the potential to decrease the profitability of the industry. Diminishing profits have a tendency to make airlines seek emission reduction measures and have the potential to trigger technological change in the long run. Profitability is closely linked to the ability to pass on cost increases to consumers. Increased costs for consumers decreases demand for airline services based on the price elasticity of demand for airline travel. There is a wide range of estimates for the price elasticity of demand for airline services: from 0 to -3.2, depending upon the traveller class and the airline's business model (Gillen et al, 2007 and Brons et al, 2002). If demand is relatively inelastic, i.e. the price elasticity of demand is less then – 1, then airlines will pass on all, or the majority, of cost increases to consumers. If the demand is elastic (the price elasticity of demand more than – 1) then, however, it is unlikely that the cost increases will be passed through. Results from a study on impacts of the EU ETS on airfares (Vivid, 2008) and evidence from the UK Air Passengers Duty (Mayor and Tol, 2007) show that 100% cost pass through is likely to happen.

E3ME does not consist of an explicit transport sub-model - it is not possible to look at the impacts on revenue tonne kilometres (RTK). However, the model can be used to investigate changes in domestic demand for air transport services in monetary terms (at 2000 prices). Results from E3ME suggest that that there will be a slight decrease in demand for air transport services by 2020: 0.04% for an allowance price of €5, 0.54% for an allowance price of €20, and 0.98% by an allowance price of €40, compared with no action reference scenarios. These decreases in demand are smaller than those observed in previous literature. The impacts assessment in the EC staff working document (SEC, 2006) shows that fully passing on the costs of allowances and opportunity costs to consumers results in a maximum 1.9%

decrease in RTKs (by allowance price €30 per tonne of CO_2 and low price elasticity). A report by CE Delft (2005) gives similar results under different assumptions - a maximum decrease of 2.1% in revenue tonne kilometres compared with a business as usual scenario. The smaller impacts on demand for air transport that were observed with E3ME are attributable to feedbacks from other industrial sectors in the model - namely, the decrease in economic activity in the aviation sector is partly offset by increased income generated from substitute activities.

Impacts on carbon emissions

Carbon emission reductions for the aviation industry are generally assumed to originate from reduced revenue tonne kilometres and fuel efficiency improvements. The current technology in the aviation market is argued to be mature (Kroo, 2004), so dramatic improvements in fuel efficiency require fundamental changes to airframes or to engines. Observed studies assume that the aviation sector is not able to reduce its emissions by more than 1% to 1.5% per kilometre flown per annum. This number comes from improvements in fuel efficiency due to improvements in currently used technologies (Morrell, 2007; Schneelhase and Grimme, 2007; SEC, 2006; Frontier Economics, 2006; CE Delft, 2005 and 2007). In light of this, BAU carbon emissions from flights in the EU will roughly double from 2005 to 2020 (Ernst and Young, 2007; CE Delft 2007; SEC, 2006). Additional fuel efficiency improvements may be available in the near future through emerging technological changes. Taking into account the long life-spans of current aircraft, however, these changes are not expected to have significant impact on fuel efficiency improvements before 2020.

CO_2 emissions from aircraft, therefore, will continue increasing and the industry is expected to cover its increasing emissions by purchasing allowances from other sectors covered by EU ETS (e.g. the power sector), and by using credits from the other Kyoto flexible mechanisms. However, modelling carried out with E3ME suggests that total CO_2 emissions in 2020 from the air transport sector will diminish in response to increasing ticket prices by 0.3% in response to an allowance price of €5, but 3.4% and 7.4% to an allowance price of €20 and €40 respectively (Figure 3).

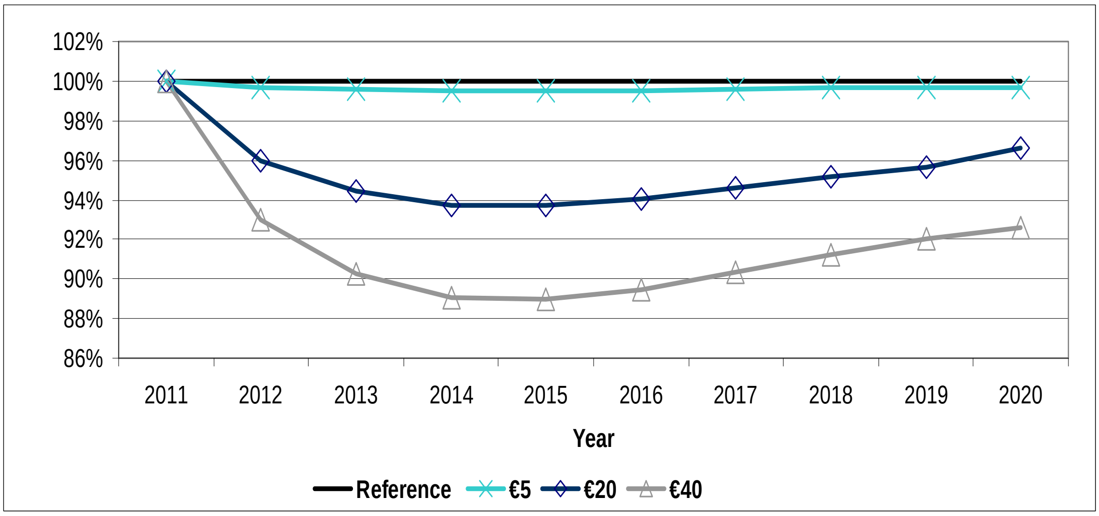

Figure 3. Reductions in CO_2 emissions from air transport compared to reference scenarios (CO_2 emissions from reference scenarios are equal to 1)

EUA	2012	2013	2014	2015	2016	2017	2018	2019	2020
€5	-0.32%	-0.44%	-0.49%	-0.49%	-0.45%	-0.41%	-0.36%	-0.33%	-0.30%
€20	-3.99%	-5.56%	-6.27%	-6.29%	-5.95%	-5.42%	-4.86%	-4.39%	-3.40%
€40	-6.98%	-9.70%	-10.97%	-11.03%	-10.54%	-9.68%	-8.74%	-7.93%	-7.39%

Table 2. Reductions in CO_2 emissions from air transport compared to reference scenarios (CO_2 emissions from reference scenarios are equal to 1)

Expected emissions reductions are larger than those in the previous literature. These originate from responses (through elasticities in the model) to increased fuel and ticket costs that are estimated based on historical data in the model. E3ME does not restrict transition to less carbon intensive technologies although these technologies are not specified in the model. Some of the carbon reduction may stem from measures that are efficient even in the absence of an emissions trading scheme or a carbon tax (see Stratus, 2005). For example, optimising the amount of fuel and water carried on board or using continuous decent.

5.2 Impacts on general macroeconomic activity in EU and its Member States

Impacts on general macroeconomic activity

A report of Frontier Economics (2006) ordered by the European Low Fares Airline Association (ELFAA) argues that macroeconomic benefits induced by the aviation industry outweigh the costs of the environmental damage it causes. The study is concerned that emissions trading in aviation compromises the growth of GDP, but this assertion is not supported by a detailed analysis. The European Commission has assessed the macroeconomic impacts of incorporating aviation in the EU ETS (SEC, 2006).

Impacts on the GDP in the EU are predicted to be between – 0.002% and 0.026% over the 10 year trading period. The decrease in economic activity in the aviation sector was assumed to be offset by increased income and employment generated from substitute activities. The current study supports the latter findings by showing almost no changes in GDP. By 2020, changes in real GDP (base year 2000) with and without inclusion of air transport as a part of EU ETS might be 0.022% (allowance price of €40), and the medium and low price scenario show no change. Therefore, adding air transport to the EU ETS is not expected to have negative impacts on economic growth in the EU or to reduce the EU's competitiveness relative to the rest of the world.

This result, however, depends crucially on the equal applicability of the emission trading scheme to all airlines that operate in the EU. If non-EU airlines were able to avoid the emission trading scheme, EU based non-EU airlines would be able to gain market share. Thus, instead of reallocating economic activity to non-aviation sectors, economic activity would be redirected to non-EU nations. There may also be leakage opportunities for non-EU carriers if they were included in the scheme, e.g. flying into a destination close to the EU instead of flying into the EU. The magnitude of potential leakage under the current proposal has not yet been estimated.

At the EU level, including aviation in the emissions trading scheme may result in change of yearly CO_2 emissions by 0.09% (allowance price of €5), 0.23% (an allowance price of €20) and – 0.23% (allowance price of €40) in 2020 compared with no action scenarios. This suggests again that the aviation sector will be a net buyer of allowances under the EU ETS, and that emission reductions have to be made in other sectors to cover the demand of allowances by the aviation sector. Additionally, these numbers reflect the relatively small share of the air transport industry in the EU ETS.

Impacts on the EU Member States

Particular regions will fare better or worse depending on the extent to which their economies are dependent on airline services and the business models of the airlines servicing the area. In particular, nations or regions predominantly served by discount airlines, that serve travellers with greater price sensitivity, may suffer larger impacts. It is argued that including aviation in the EU ETS may have particularly negative consequences for the new EU Member States, slowing down their economic growth and decreasing their welfare (Frontier Economics, 2006). This report does not give evidence supporting these arguments. In the current study, GDP rates are affected slightly more in old Member States than in new ones. This is the opposite result to that in the literature. For example, in 2020 the change in UK GDP will be about - 0.002% compared to Polish GDP which may increase by 0.024% (allowance price of €40) in comparison to no action scenarios. Related reductions in CO_2 emissions will be - 0.193% and -0.001 respectively. These results can be explained by the fact that old Member States have more developed air transport sectors that count for a larger share in their GDP and CO_2 emissions (e.g. 6.3% of total UK CO_2 emissions in 2005 - DfT, 2009) . Therefore policies that impose extra costs on air transport in these countries may result in larger impact on GDP. Also increasing costs in old Member States may give some advantage to some of the new Member States were for example labour costs are lower. These developments can lead towards carbon leakage inside the EU itself.

6 Auctioning allowances

Impacts of different allocation methods are widely studied (e.g. CE Delft, 2005; Morell, 2007). There are two kinds of allocation methods in the EU ETS: free allocation and auctioning. These are often confused with methods that are used for computing the amounts of allowances (caps) to be allocated – namely grandfathering[7] and benchmarking[8] (see for example Morell, 2007). During an auction, airlines need to bid for carbon allowances based on expected CO_2 emissions for the coming trading year. Literature supports auctioning as the best allocation method for distributing allowances to the airlines. Auctioning is seen as a fair method (especially for new entrants) and it also helps to avoid windfall profits that may occur when the opportunity costs are passed on to consumers (Sijm et al, 2006). However, auctioning imposes additional costs on the airlines and the impact of these costs depends upon cost pass-through rate. Macroeconomic impacts depend heavily on created auctioning revenues and how these revenues are used (Ekins and Barker, 2001; SEC, 2006). In this study, all costs for allowances were passed through to consumers. All auctioning revenues were used to increase government expenditures. There were no auctioning revenues recycled, e.g. no revenues were used to reduce regional employers' contributions to social security.

In this study, three scenarios were used to assess the impact of auctioning upon the industry and the economic activity in the EU. Reference scenarios A and B (see Table 1 and Figures 1 and 2) differ according to the levels of auctioning. Reference scenario A has a fixed auctioning level of 15% as it stands in the current legislation for the aviation emissions trading. Reference scenario B follows the proposal for the EU ETS trading phase 3 and has 15% of auctioning in 2012, then 20% in 2013 which will thereafter increase up to 100% in 2020. Scenario MIN has no auctioning and all allowances are allocated at no cost.

In this study, the different levels of auctioning have no significant impact on the CO_2 emissions from the industry. This is because the study assumes 100% cost pass through to consumers. Thus the auctioning of allowances impacts industry's profits. However, from a macroeconomic perspective there

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[7] Method of calculating the amount allowances to be allocated that is based on historical emissions.

[8] Method of calculating the amount allowances to be allocated that is based on some kind of technical or operational performance criterion.

are significant differences depending upon percentage of allowances auctioned and how the auctioning revenues are used (Table 3).

Scenario (allowance price)	Industrial output	CO_2 emissions from the industry	EU GDP	EU CO_2 emissions
A (€5)	-0.038	-0.302	0.000	0.090
B (€5)	-0.035	-0.301	0.006	0.091
MIN (€5)	-0.039	-0.304	-0.001	-0.057
A (€20)	-0.544	-3.402	0.000	0.237
B (€20)	-0.502	-3.394	0.106	0.253
MIN (€20)	-0.563	-3.409	-0.041	-0.068
A (€40)	-0.975	-7.392	0.022	-0.297
B (€40)	-0.892	-7.376	0.227	-0.265
MIN (€40)	-1.012	-7.397	-0.055	-0.315

Table 3. Impacts of including aviation in the EU ETS (in percentage changes) under different levels of auctioning relative to reference scenarios with an allowance price of €5, €20 and €40 in 2020

At the industry level, there are negligible differences depending upon the level of auctioning used. High level of auctioning (Scenario B) gives slightly less reduction in economic activity (up to 0.1%) and CO_2 emissions (0.01%). These numbers are driven by the assumption that auctioning revenues are used to increase government spending that expands economic activity in the region. Also we have assumed that there will be no emission reduction targets for non-EU ETS sectors. Rise in overall economic activity partly offsets the decrease in demand for air transport services caused by including the industry in the EU ETS. The numbers will be different if the auctioning revenues are recycled or invested in R&D.

High levels of auctioning may lead to increased CO_2 emissions in the EU, if the revenues are used to increase government spending and thereby generate more economic activity. This holds for lower allowance prices (€5 and €20). In this study, government spending is spread equally between defence, education, health and other spending. For example, these activities are often intensive users of surface transport that is not covered by the EU ETS. Therefore increasing activities in these sectors tends to also increase CO_2 emissions. However, higher allowance prices put more pressure on trading sectors and have a potential to reduce CO_2 emissions significantly in the whole economy. There will still be an increase in economic activity, but this will not be high enough to offset the reductions in carbon emissions.

7 Impacts of credits from CDM projects

The EU emissions trading scheme allows credits to be used from the two other Kyoto flexible mechanisms – CDM and JI projects. The credits from these two projects are to cover the need for extra allowances that may be required under the emissions trading. The European carbon market counts for about 90% of the global market for CDM credits (CERs). In phase 2 (i.e. 2008-2012), it is possible to use credits from CDM and Joint Implementation (JI) up to about 13.4% (i.e. about 1.4 billion credits) of allocated emissions (NAPs, 2008). The linking directive stresses that the use of CDM/JI credits is to be supplementary to domestic GHG reductions. Unused credits from phase 2 are transferable (bankable) to phase 3 compliance. If there is no post-Kyoto agreement after 2012, then companies can only use these banked CERs during phase 3 and no new CERs will be used. If such an agreement is reached, there will be an automatic change which allows 50% of the additional reductions (the EU CO_2 reduction target will be then lowered from 20% to below 2020 levels) to be achieved by credits. If there is no international agreement, then the proposed scheme is unfair on new entrants, because industries that enter into phase 3 (or within phase 2) cannot transfer the same amount of credits from the earlier phase to phase 3. Air transport that enters the EU ETS in 2012 is one such industry.

In 2012, the air transport industry can use CDM credits (CER) to cover the demand for extra allowances. These credits can account for up to 15% of the EU ETS allocation and are supplementary to the original allocation. From 2013 onwards, the usage of CERs is subject to the ongoing review of the EU's general Emissions Trading Scheme.

In early 2008, the price of a CER in the primary market was in the range of €8 - €13 (Capoor and Ambrosi, 2008). In the secondary markets, the prices, which were around €16 - €17, have been following the European carbon allowance market. Therefore it is unlikely that the CER price will go under the price level set by the primary market. Figure 4 below shows the declining prices in the future markets of both CERs and EUAs, which are likely to be caused by the present economic downturn and falling oil prices. Thus, if the allowance price in the EU carbon market falls under €13, then it is unlikely that the CER will be traded as part of the EU ETS.

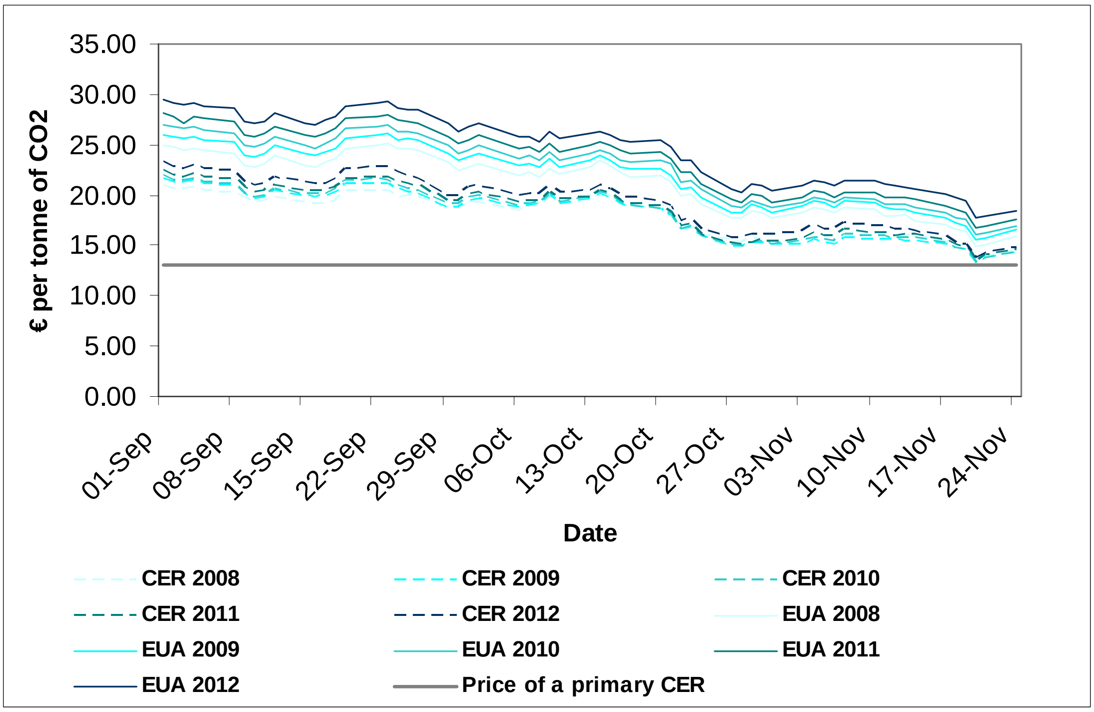


Figure 4. The future market of CERs and EUA for the EU ETS phase 2 (2008-2012). Source: EEX, 2008

Figure 4 above shows that the differences between CER and EUA futures have narrowed between September and November 2008, which indicates that the secondary CER market has begun to bottom out.

CERs are generally cheaper than EUA to attract the companies that are trading under the EU ETS to buy these credits. This difference in price seems to be the risk premium related to uncertainties related to deliveries of future CERs. Using cheaper CERs instead of EUAs will help reduce the costs of carbon mitigation. On the other hand, CERs are issued in developing countries and this means monetary outflow for the European economy. However, the amount of CERs that airlines can use is limited to 15% of their 2012 allowance allocations. The limit is set to ensure that the majority of carbon emission reductions will be achieved within the EU.

We have assumed that CERs are purchased only if the allowance price is €20 and €40 (Table 3), and will cost €18 and €36 respectively. As expected, the air transport industry will reduce their emissions slightly more if they cannot use CERs (scenario A1 and B1). This is due to higher costs that are passed on to consumers. On the other hand, substituting CERs for EAUs will help airlines gain savings as the CER price is about 10% below allowance price.

For the EU as a whole, the use of CERs has a slightly negative impact on the GDP and results in less reduction of CO_2 emissions in the EU. This fall in EU carbon mitigation is offset (by design) from emission reductions in developing countries.

Scenario (allowance price)	Industrial output	CO_2 emissions from the industry	EU GDP	EU CO_2 emissions
A (€20)	-0.544	-3.402	0.000	0.237
A1 (€20)	-0.529	-3.422	0.024	0.230
B (€20)	-0.502	-3.394	0.106	0.253
B1 (€20)	-0.487	-3.414	0.129	0.232
A (€40)	-0.975	-7.392	0.022	-0.297
A1 (€40)	-0.948	-7.423	0.061	-0.312
B (€40)	-0.892	-7.376	0.227	-0.265
B1 (€40)	-0.865	-7.408	0.266	-0.284

Table 4. Impacts of including aviation in the EU ETS (in percentage changes) relative to reference scenarios with an allowance price of €5, €20 and €40 (A and B scenarios are including usage of CERs; A1 and B1 excluding CERs) in 2020

8 Oil prices *versus* carbon prices

One important factor presently included in the model through an external scenario is the price of oil. Clearly, the cost of oil has an important effect on the economy of each nation and on the cost and demand for the aviation sector. Recent events have shown us that the oil price is very volatile, having risen to 150$/b in July 2008 and fallen to under 50$/b in November 2008. This strong price increase was the result of a relatively small excess of demand over supply and the expected increasing demand coming particularly from China. The spectre of global recession and the fall in demand has led to the halving of oil prices in three months. Over the next decade however, assuming that there is a recovery within the next five years, we shall start to see the real impacts of the falling supply of conventional oil, and this suggests that we shall see a serious increase in oil prices.

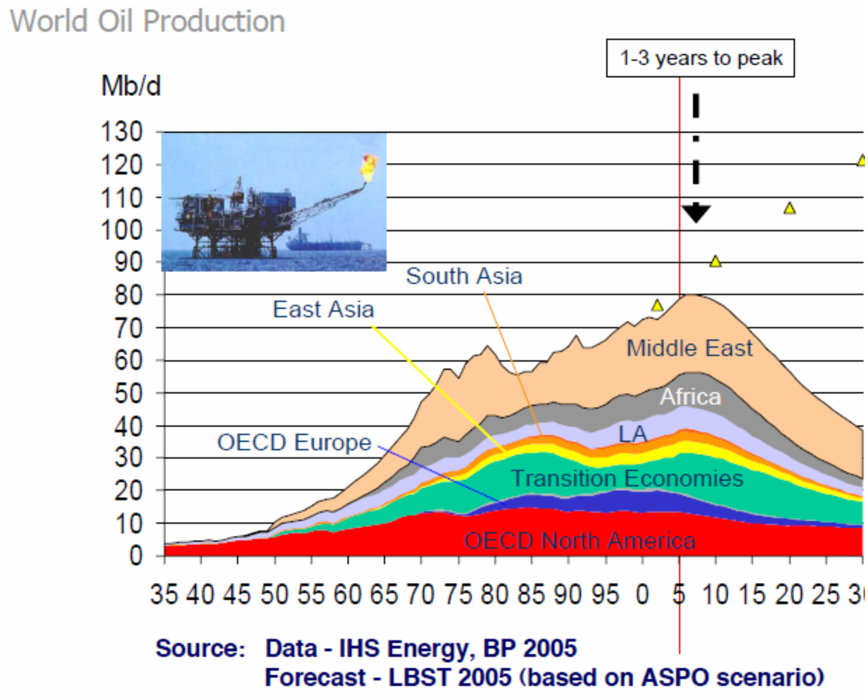


Figure 5. The forecast total oil production will start to decline in the next few years. (Maltini, 2008) (LBST: Ludwig-Bolkow-Systemtechnik/European Hydrogen Association, 2005)

The likelihood therefore is that oil prices will increase very significantly over the next decade. Of course, this price increase will have a double effect: it will exclude those consumers that cannot afford it, and it will allow the exploitation of sources that were previously not viable economically. This would, however, not bring the price down but simply affect the rate at which it will rise. Figure (6) shows how events have affected oil prices in the period since 1947, and increasing global oil demand will put more upward pressure on prices.

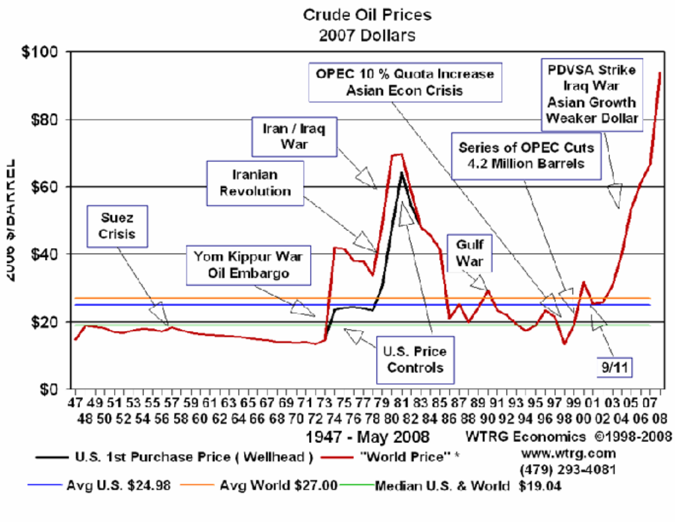
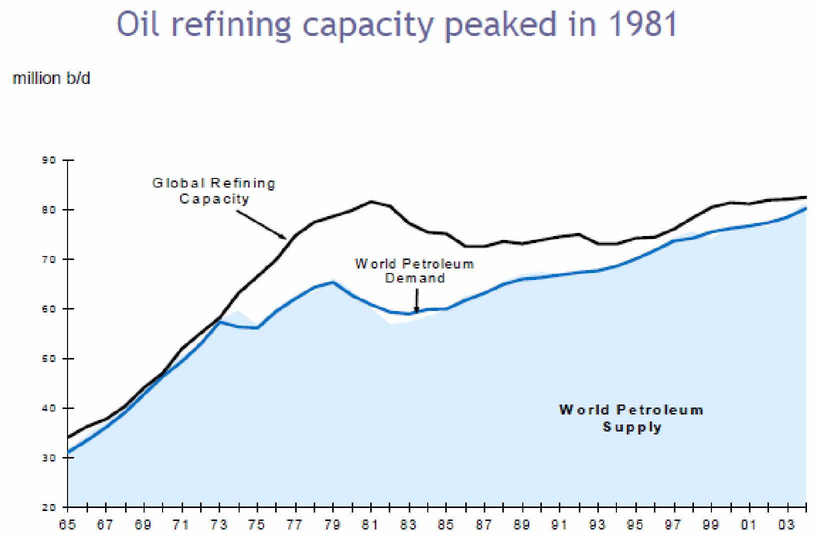


Figure 6. The effect of various events since 1947 on crude oil prices. (WRTG Economics, 2009)

A further complication is that the economy and aviation are impacted by both crude oil and refined product prices. In addition to oil supplies being overtaken by demand, refinery capacity is also becoming a bottleneck that limits supply and raises the cost of refined products such as aviation fuel. This implies that prices for oil and oil products will likely increase significantly over the next decade.


Oil refining capacity peaked in 1981

Source: IEA and Goldman Sachs Commodity Research.

Figure 7. Global demand is reaching the limits of current refining capacity

Overall then, future oil costs are likely to increase considerably, which will partially achieve the aims of the carbon trading scheme by reducing consumption and emissions. It may well be that the effects of the lower carbon price scenarios will be dwarfed by those of the high oil and energy prices. Carbon trading will tend to focus increased efficiency on the sectors that have lowest abatement costs, but in the longer term, energy reducing innovations will probably be driven as much by increasing energy and oil costs as by capping carbon emissions.

The effect from increased fuel prices is comparable with the effects of increased carbon costs. This is because CO_2 emissions are directly derived from the amount of fuel consumed. In this study, we have investigated the effect of high fuel prices on air transport and its CO_2 emissions. For 2008 the reference scenario assumes that the oil price has remained at the average level of 2007, i.e. 60 $/b, and will increase after that at the rate of inflation (i.e. 2.5%). Three oil price scenarios were used explore the effects of oil prices: a low, medium and high oil price scenario (Table 4). All scenarios assume that EU ETS is active and the carbon price is €20, but without the air transport sector included in it.

Scenario	**Average oil price 2007**	**Average oil price 2008**	**Average oil price 2009**	**Annual average oil price change 2010- 2020**
OIL high	60 $/b	95 $/b	97 $/b	+2.5%
OIL medium	60 $/b	95 $/b	75 $/b	+2.5%
OIL low	60 $/b	95 $/b	75 $/b	+1.5%
OIL ref	60 $/b	61 $/b	62 $/b	+2.5%

Table 5. Oil price scenarios used in the study

As expected, the sensitivity analysis shows that the increase in oil prices has resulted in a decrease in carbon emissions from the aviation sector (Figure 8). The finding is consistent with the fact that fuel costs amount for high part of airlines' operating costs (e.g. 24.5% in 2007 – AEA, 2008), and therefore increasing fuel costs are putting downward pressure on demand in the industry.

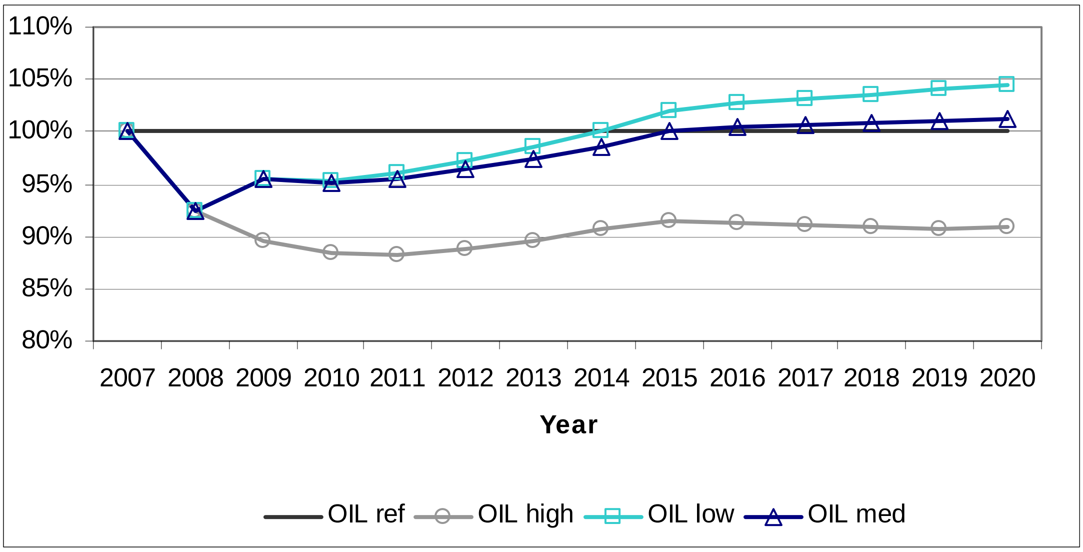


Figure 8. Oil price impacts on CO_2 emissions from the air transport sector relative to the reference scenario (OIL ref = 1)

The study shows that the oil price shock in 2008 might have already resulted in a carbon reduction of 7% for 2008. If the crude oil price remains high (95 $/b (2008) – OIL high), then CO_2 might remain about 10% below the base line over a longer time period (2009 – 2020). If the average oil price is 75 $/b in 2009 (OIL med) and remains there, then the industry may adjust gradually to the new situation and carbon emissions will rise, gradually returning to the 2007 level by 2015. However, if the crude oil price starts to rise by 1% after 2009 (OIL low), then the original CO_2 will be achieved a year earlier.

One interesting issue that emerges from the discussion above is how these reductions compare with the impacts of including the air transport industry in the EU ETS. We have indexed the CO_2 emission reductions and placed figures 3 and 8 on top of each other (Figure 9). The figure suggests that the oil price shock in 2008 is comparable with the impact of a high carbon price of €40.

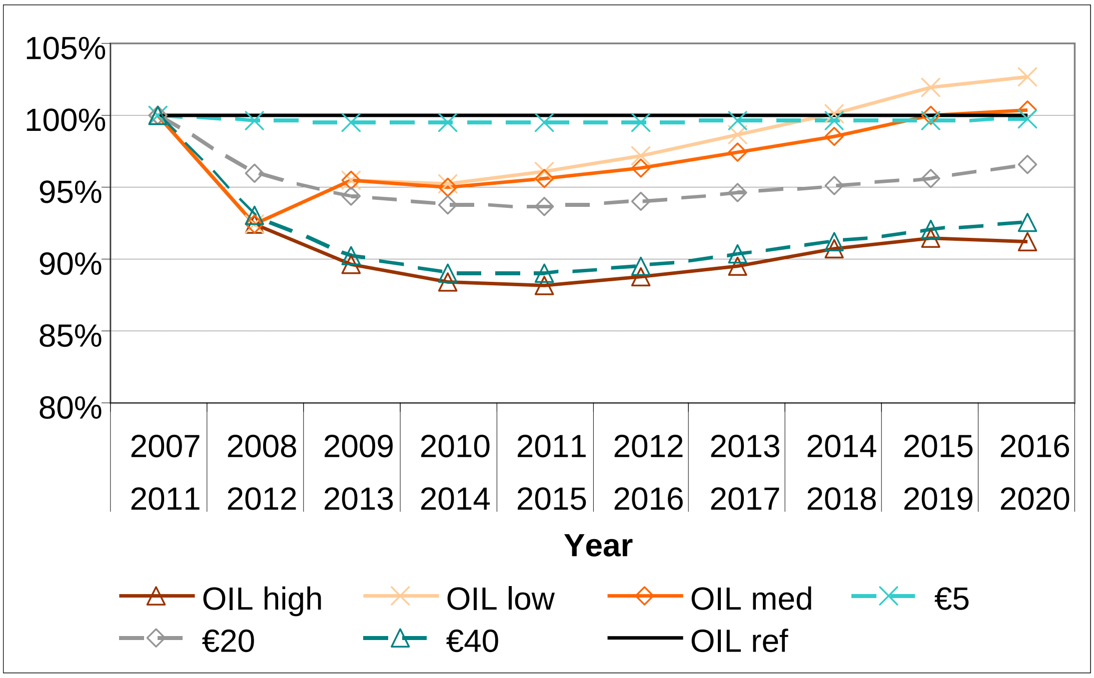


Figure 9. Oil price impacts (2007-2016) compared with carbon price impacts (2011-2020) on CO_2 emissions from the air transport industry (reference scenarios = 1)

Although the impact of oil price shock on CO_2 emissions is comparable with a carbon price impact of €40 per tonne of CO_2 the macroeconomic effects of high oil price (scenario OIL high) will be more severe and may result up to 3% loss in annual GDP by 2020 (compared with OIL ref). Also under OIL high scenario the air transport sector's output in the EU is likely to be about 2% lower by 2020. These results reflect the European economy's dependency on imported oil products. The money paid for oil will not stay inside economic area and enhance domestic economy opposed to the revenues from carbon allowances.

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Annex: Description of the E3ME model

(Source: Cambridge Econometrics, 2008)

E3ME: An Energy-Environmental-Economy Model of Europe

The E3ME model has been built by a European team under the EU JOULE/THERMIE programme as a framework for assessing energy-environment-economy issues and policies. The model has been used for general macro and sectoral economic analysis and for more focused analysis of policies relating to greenhouse gas mitigation, incentives for industrial energy efficiency and sustainable household consumption. Its pan-European coverage is appropriate for an increasingly integrated European market. E3ME provides an econometric one-model approach in which the detailed industry analysis is consistent with the macro analysis: in E3ME, the key indicators are modelled separately for each sector, and for each region, yielding the results for Europe as a whole.

- The E3ME model provides annual comprehensive forecasts to the year 2030:
    - for 27 European regions including the EU25 (as of 2006), Norway and Switzerland
    - for industry output, investment, prices, exports, imports, employment and intermediate demand at a 42-industry level including 16 service industries – for consumers' expenditure in 28 categories
    - For energy demand, split by 19 fuel uses of 12 fuels, and environmental emissions.
- Full macro top-down and industrial bottom-up simulation analysis of the economy, allowing industrial factors to influence the macro-economic picture
- An in-depth treatment of changes in the input-output structure of the economy over the forecast period to incorporate the effects of technological change, relative price movements and changes in the composition of each industry's output
- Dynamic multiplier analysis, illustrating the response of the main economic indicators, industrial outputs and prices to standard changes in the assumptions, eg changes in world oil prices, income taxes, government spending, and exchange rates
- Scenario analysis, across a range of greenhouse gas mitigation policies in Europe, including carbon taxes and permit trading

The Purpose and Design of E3ME

The Policy Analysis of Long-Term E3 Interactions

E3ME is intended to meet an expressed need of researchers and policy makers for a framework for analysing the long-term implications of Energy-Environment-Economy (E3) policies in Europe, especially those concerning R&D and environmental taxation and regulation. The model is also capable of addressing annual short-term and medium-term economic effects as well as, more broadly, the long-term effects of such policies over the next 20 years, such as those from the supply side of the labour market.

Most conventional macroeconomic models which are operational in government describe short and medium-term economic consequences of policies but with a limited treatment of long-term effects, such as those from the supply side of the labour market, and this limits their ability to analyse long-term policies. In contrast, Computable General Equilibrium (CGE) models, have been widely used to analyse long-term E3 policies. CGE models specify explicit demand and supply relationships and enforce market clearing, and are therefore seen as desirable characterizations of long-term outcomes in which markets are assumed to be in equilibrium; for this reason they have been developed particularly in the US for the analysis of environmental regulation. However, CGE models are not generally estimated by time-series econometric methods and they have not typically been subjected to rigorous historical validation, either in terms of the values of the model's parameters or, more broadly, the underlying assumptions with respect to economic behaviour. They also typically tend to impose the dynamics of the model solution, and so cannot be used for historical validation of the overall model; the analysis of short- and medium-term impacts of policy changes, meanwhile, tends to arise from the assumptions inherent in the model. Their use in forecasting or scenario projections is therefore more limited. Therefore, CGE models are not necessarily the most appropriate vehicle for understanding the process of dynamic adjustments and structural change at the sectoral level.

E3ME combines the features of an annual short- and medium-term sectoral model estimated by formal econometric methods with the detail and some of the methods of the CGE models, providing analysis of the movement of the long-term outcomes for key E3 indicators in response to policy changes. It is essentially a dynamic simulation model of Europe estimated by econometric methods.

The Method: Long-Term Equations and Short-Term Dynamic Estimation

The econometric model, in contrast with some macroeconomic models currently in operation, has a complete specification of the long-term solution in the form of an estimated equation which has long-term restrictions imposed on its parameters. Economic theory, for example the recent theories of endogenous growth, informs the specification of the long-term equations and hence properties of the model; dynamic equations which embody these long-term properties are estimated by econometric methods to allow the model to provide forecasts. The method utilises developments in time-series econometrics, with the specification of dynamic relationships in terms of error correction models (ECM) which allow dynamic convergence to a long-term outcome. E3ME is therefore a relatively ambitious modelling project which expands the methodology of long-term modelling to incorporate developments both in economic theory and in applied econometrics, while at the same time maintaining flexibility and ensuring that the model is operational.

The Model and the Research Strategy

E3ME is a detailed model of 42 industrial sectors with the disaggregation of energy and environment industries, in which the energy-environment-economy interactions are central.

The model is designed to be estimated and solved for 27 regions of Europe (the EU-25 Member States in 2006 plus Norway and Switzerland). For the ten Member States that joined the EU in 2004, shrinkage methods are applied to the raw data to estimate long-term parameters from relatively short data series (1993-2004).

This one-model approach is distinguished from the multi-model approach, which is a feature of earlier model-based research for the EU. In principle, linked models (such as the DRI or the HERMES-MIDAS system of models) could be estimated and solved consistently for all the economies involved. However, in practice, this often proves difficult, if not impossible, and considerable resources have to go into linking. Even if the consistency problem in linkage can be solved by successive iterative solutions of the component models, there remains a more basic problem with the multi-model approach if it attempts to combine macroeconomic models with detailed industry or energy models. This problem is that the system cannot adequately tackle the simulation of `bottom-up’ policies. Normally these systems are first solved at the macroeconomic level, then the results for the macroeconomic variables are disaggregated by an industry model. However if the policy is directed at the detailed industry level (say, a tax on the carbon content of energy use), it is very difficult (without substantial intervention by the model operator) to ensure that the implicit results for macroeconomic variables from the industry model are consistent with the explicit results from the macro model. As an example, it is difficult to use a macro-industry two-model system to simulate the effect of exempting selective energy-intensive industries from the carbon/energy tax.

Comparative Advantages of E3ME

E3ME has the following advantages over many competing models:

- Model disaggregation: The detailed nature of the model allows the representation of fairly complex scenarios, especially those that are differentiated according to sector and to country. Similarly, the impact, of any policy measure can be represented in a detailed way.

- Econometric pedigree: The econometric grounding of the model makes it better able to represent and forecast performance in the short to medium run. It therefore provides information that allows for dynamic responses to changes in policy and that is closer to the time horizon of many policy makers than pure CGE models, which provide long-term equilibrium solutions.

- E3 linkages: E3ME is a hybrid model. An interaction (two-way feedback) between the economy, energy demand/supply and environmental emissions is an undoubted advantage over models that may either ignore the interaction completely or only assume a one-way causation. For example, the EU ETS includes a cap on CO_2 emissions: the model can be used to solve for the CO_2 allowance price, allowing for effects on electricity prices and demand, as well as on macroeconomic variables.

Summary of the Characteristics of E3ME

In summary, the characteristics of E3ME are such that the model is:

- elaborated at a European rather than at a national level, with the national economies being treated as regions of Europe

- dealing with energy, the environment, population and the economy in one modelling framework

- designed from the outset to address issues of central importance for economic, energy and environmental policy at the European level

- capable of providing short- and medium-term economic and industrial forecasts for business and government

- based on a system of dynamic equations estimated on annual data and calibrated to recent outcomes and short-term forecasts

- capable of analysing long-term structural change in energy demand and supply and in the economy

- focused on the contribution of research and development, and associated technological innovation, on the dynamics of growth and change.

The Theoretical Background to E3ME

Economic activity undertaken by persons, households, firms and other groups has effects which transmit to other groups, sometimes after a lag, and the effects persist to include future generations, although many of the effects soon become so small as to be negligible. But there are many such groups, and the effects, both beneficial and damaging, accumulate in economic and physical stocks. The effects are transmitted through the environment, with externalities such as greenhouse gas emissions leading to global warming, through the economy and the price and money system via the markets for labour and commodities, and through the global transport and information networks. The markets mainly transmit effects through the level of activity creating demand for inputs of materials, fuels and labour, through wages and prices affecting incomes and through incomes in turn leading to further demands for goods and services. These interdependencies suggest that an E3 model should be comprehensive, including many linkages between different parts of the economic and energy systems.

These systems are characterised by economies and diseconomies of scale in both production and consumption, by markets with different degrees of competition, by the prevalence of institutional behaviour which may be maximisation, but perhaps the satisfaction of more restricted objectives, and by rapid and uneven changes in technology and consumer preferences, certainly within the time scale of greenhouse gas mitigation policy. Labour markets in particular may be characterised by long-term unemployment. An E3 model to represent these features must be flexible, capable of embodying a variety of behaviours and capable of simulating a dynamic system. The approach can be contrasted with that of general equilibrium models, which usually assume constant returns to scale, perfect competition in all markets, maximisation of social welfare measured by total discounted private consumption, no involuntary unemployment, and exogenous technical progress following a constant time trend (see Barker, 1998, for a discussion).

E3ME as an E3 Model

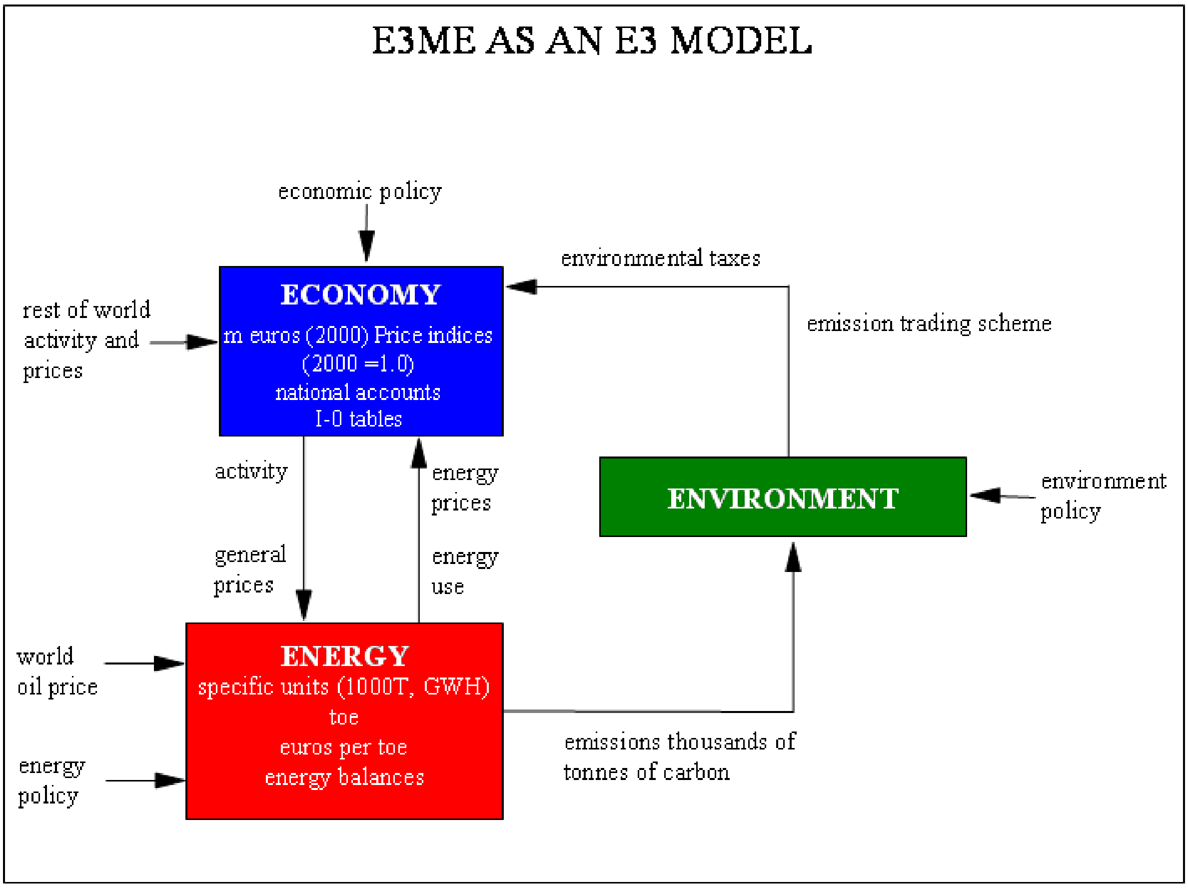
The model comprises:

- The accounting balances for commodities from input-output tables, for energy carriers from energy balances and for institutional incomes and expenditures from the national accounts

- Environmental emission flows

- 22 sets of time-series econometric equations, covering energy demand, the labour market, prices and the components of GDP, with two different disaggregate consumption specifications and optional transport equations.

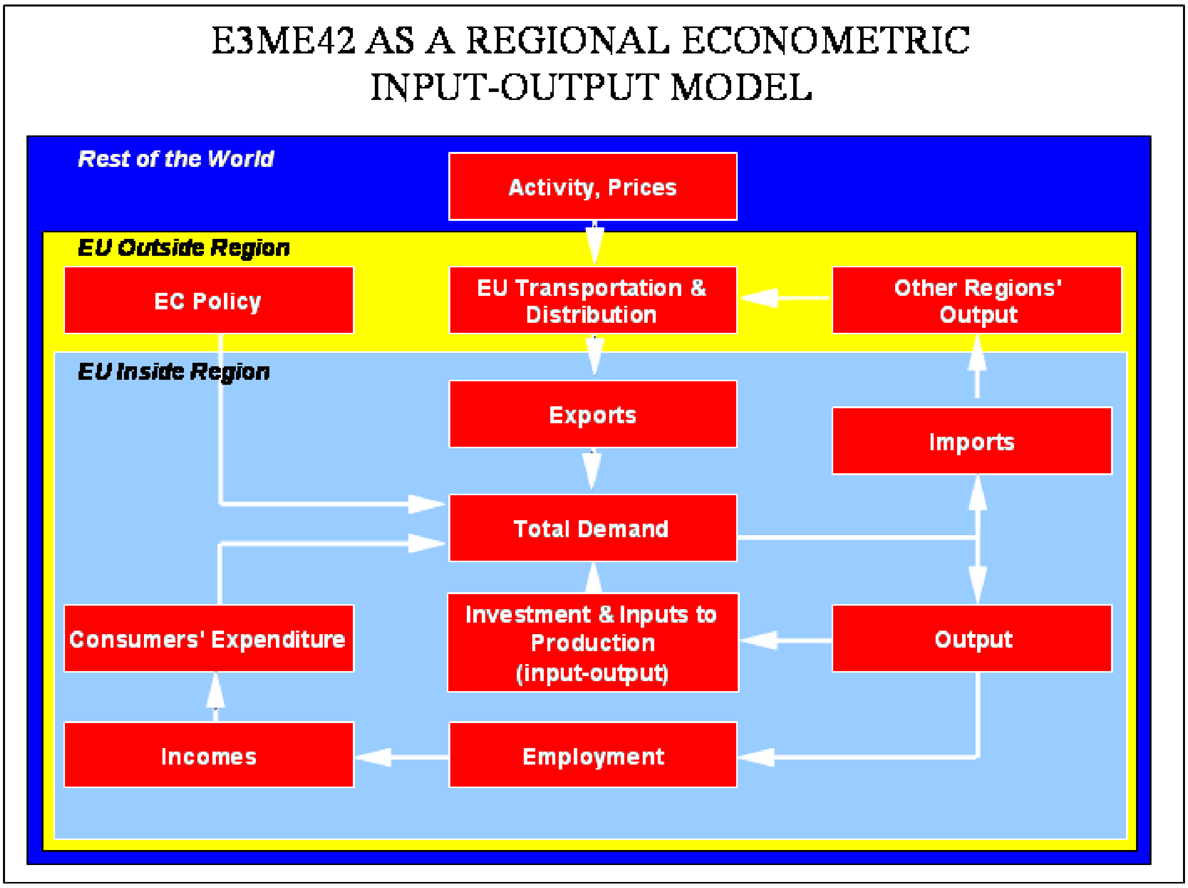
The chart: E3ME as an E3 model shows how the three components of the model - energy, environment and economy - fit together. Each component is shown in its own box and utilises its own units of account and sources of data. Each data set has been constructed by statistical offices to conform with accounting conventions. Exogenous factors coming from outside the modelling framework are shown as inputs into each component on the outside edge of the chart. For the EU economy, these factors are economic activity and prices in non-EU world areas (the world areas distinguished in the model are listed below in Chapter 5) and economic policy (including tax rates, growth in government expenditures, interest rates and exchange rates). For the energy system, the outside factors are the world oil prices and energy policy (including regulation of energy industries). For the environment component, exogenous factors include policies such as reduction in SO emissions from large combustion plants. The linkages between the components of the model are shown explicitly with arrows showing which values are transmitted between components.



The economy module provides measures of economic activity and general price levels to the energy module; the energy module provides emissions of the main air pollutants to the environment module, which in turn indicates damages to health and buildings (this effect is not yet included in the formal model). The energy module provides detailed price levels for energy carriers distinguished in the economy module and the overall price of energy as well as energy use in the economy.

E3MG as a Regional Econometric Input-Output Model

The chart E3ME46 as a regional econometric input-output model shows how the economic module will be solved as an integrated EU regional model. Most of the economic variables shown in the chart are at a 42-industry level. The whole system is solved simultaneously for all industries and all 27 regions (although the software allows a single-region solution, with the other regions at base-projection values). The chart shows interactions at three spatial levels: the outermost area, encompassing the others, is the rest of the world; the next level is the European Union outside the region in question; and finally, there are the relationships within the region.



The chart shows three loops or circuits of economic interdependence, which are described in some detail below. These are the export loop, the output-investment loop and the income loop.

E3ME's export loop

The export loop runs from the EU transport and distribution network to the region's exports, then to total demand. The region's imports feed into other EU regions' exports and output and finally to these other regions' demand from the EU pool and back to the exports of the region in question. It should be noted that activity in the rest of the world is treated as exogenous and so E3ME will not produce this feedback effect from exports external to the EU.

Likewise, if the model is being solved for just a single region the export loop will be broken and there will be no feedback effects.

The modelling of international trade is central to this relationship. The basic assumption is that, for most commodities, there is a European 'pool' into which each region supplies part of its production and from which each region satisfies part of its demands. This might be compared to national electricity supplies and demands: each power plant supplies to the national grid and each user draws power from the grid and it is not possible or necessary to link a particular supply to a particular demand.

The demand for a region's exports of a commodity is related to three factors:

- Domestic demand for the commodity in all the other EU regions, weighted by their economic distance from the region in question
- Activity in the main external EU export markets, as measured by GDP or industrial production

- Relative prices, including the effects of exchange rate changes.

Economic distance is measured by using a set of actual bilateral trade matrices for 1997 (although there are plans to introduce a time series covering the period 1993-2002) or by a special distance variable, normalised with a weight of 1 being given to activity in the home region. For the special measure of distance, the weights for the other regions are inversely proportional to the economic distances of the other regions from the exporting region.
Regional imports are related to demand and relative prices by commodity and region. In addition, measures of innovation (based on R&D) have been introduced into the trade equations to pick up an important long-term dynamic effect on economic development.

E3ME's output-investment loop

The output-investment loop includes industrial demand for goods and services and runs from total demand to output and then to investment and back to total demand. For each region, total demand for the gross output of goods and services is formed from industrial demand, consumers' expenditure, government demand, investment (fixed domestic capital formation and stockbuilding) and exports. These totals are divided between imports and domestic output depending on relative prices, levels of activity and utilisation of capacity. Industrial demand represents the inputs of goods and services from other industries required for current production, and is calculated using input-output coefficients. Input-output tables have been obtained from Eurostat, ONS and GTAP and used to give 2000 estimates for the 27 E3ME regions. The coefficients are calculated as inputs of commodities from whatever source, including imports, per unit of gross industrial output.

Forecast changes in output are important determinants of investment in the model. Investment in new equipment and new buildings is one of the ways that companies adjust to the new challenges introduced by energy and environmental policies, so the quality of the data and the way they are modelled is of great importance to E3ME. Regional investment by investing industry is determined in the model as intertemporal choices depending on capacity output and investment prices. When investment by user industry is determined, it is converted, using coefficients derived from input-output tables, into demands on the industries producing the investment goods and services, mainly engineering and construction. These demands then constitute one of the components of total demand.

Gross fixed investment, enhanced by R&D expenditure in constant prices, is accumulated to provide a measure of the technological capital stock. There are problems with the usual definition of the capital stock (see Scott, 1989), partly because there are no satisfactory data on economic scrapping. The accumulation measure is designed to get round the worst of these problems. E3ME46 makes the distinction between ICT and non-ICT investment to capture the effects of the new economy. Investment, both in ICT and non-ICT areas, is central to the determination of long-term growth and the model embodies a theory of endogenous growth which underlies the long-term behaviour of the trade and employment equations.

E3ME's income loop

In the income loop, industrial output generates employment and incomes, which leads to further consumers' expenditure, adding to total demand. Changes in output are used to determine changes in employment, along with changes in real wage costs, interest rates and energy costs. With wage rates explained by price levels and conditions in the labour market, the wage and salary payments by industry can be calculated from the industrial employment levels. These are some of the largest payments to the personal sector, but not the only ones.

There are also payments of interest and dividends, and transfers from government in the form of state pensions, unemployment benefits and other social security benefits. Payments made by the personal sector include mortgage interest payments and personal income taxes.

Personal disposable income is calculated from these accounts, and deflated by the consumer price index to give real personal disposable income.

Totals of consumer spending by region are derived from consumption functions estimated from time-series data (this is similar treatment to that of the HERMES model). These equations relate consumption to regional personal disposable income, a measure of wealth for the personal sector, inflation and interest rates. In the subsequent allocation of this spending by commodity, the approach makes the most of the disaggregated data on consumers' expenditure available by region from Eurostat. Again sets of equations have been estimated from time-series data relating the spending per capita to the national spending using the CBS version of consumption allocation system. The incorporation of this system into the solution is complex: the allocation system has been adapted to provide the long-run income and relative price parameters in a two-stage procedure, with a standardised co-integrating equation including demographic effects providing the dynamic solution. The substitution between categories as a result of changes in relative prices is achieved at the regional level.

Introduction to Energy-Environment Modelling in E3ME

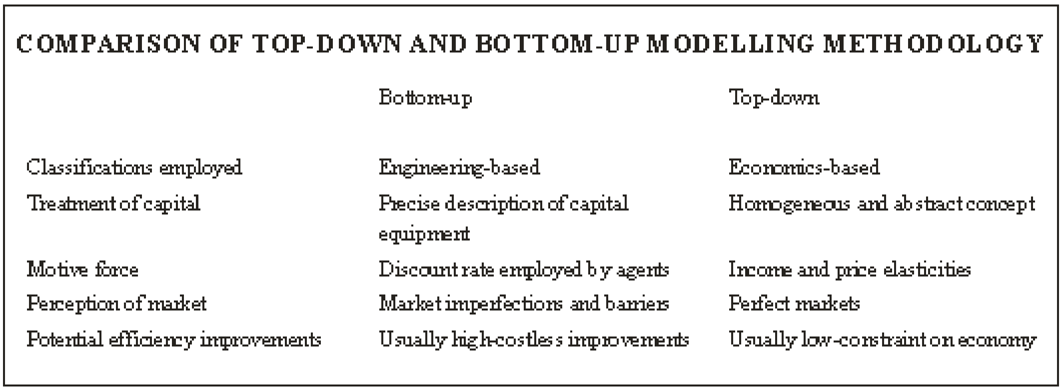
This section outlines how energy demand and prices are modelled in E3ME, and how this links into the economic modelling. This includes a discussion of top-down and bottom-up methodologies and how this is applied to E3ME, the Emissions submodel and finally feedback effects from the energy submodel to the economic model.

Top-Down and Bottom-Up approaches to E3 modelling and their use in E3ME

E3ME is intended to be an integrated top-down, bottom-up model of E3 interaction. In particular, a detailed engineering-based treatment is planned for the electricity supply industry (ESI), the demand for energy by the domestic sector, and transportation. The current version of the model is top-down, but it is important to be aware of the comparative strengths and weaknesses of the two approaches.

Top-down economic analyses and bottom-up engineering analyses of changes in the pattern of energy consumption possess distinct intellectual origins and distinct strengths and weaknesses (see chart: Comparison of top-down and bottom-up modelling methodology).

Perhaps the most significant difference is in the treatment of capital and technology. In top-down models capital is usually treated as a homogeneous input, which is related to energy only insofar as it is assumed to possess a degree of substitutability with energy inputs in production. Technological change (i.e. qualitative change in the characteristics of capital) is usually represented as an exogenous trend, sometimes explicitly related to energy consumption, affecting the productivity of the homogeneous capital input. Conversely, in bottom-up models capital is given an explicit empirical content and is related to energy in a very specific way, either in terms of generating equipment, other energy-related capital, or public infrastructure. Technological change is represented as a menu of options presently available or soon-to-be available, which enjoy increasing market penetration.



COMPARISON OF TOP-DOWN AND BOTTOM-UP MODELLING METHODOLOGY

	Bottom-up	Top-down
Classifications employed	Engineering-based	Economics-based
Treatment of capital	Precise description of capital equipment	Homogeneous and abstract concept
Motive force	Discount rate employed by agents	Income and price elasticities
Perception of market	Market imperfections and barriers	Perfect markets
Potential efficiency improvements	Usually high-costless improvements	Usually low-constraint on economy

Similarly the mechanisms which represent the driving force in the respective analyses are very different. In economic models change is usually modelled using elasticities, such as substitution between factors, or price and income elasticities. In bottom-up modelling the determinant force is captured by the relationship between technological options and usually by some notion of the discount rate employed by economic agents (households, firms and the government). In some sense, the discount rate employed in bottom-up models is the mirror image of an elasticity employed in top-down models. Both factors will determine the extent to which agents react to changes in the conditions associated with the energy supply chain (see Barker, Ekins and Johnstone, 1995).

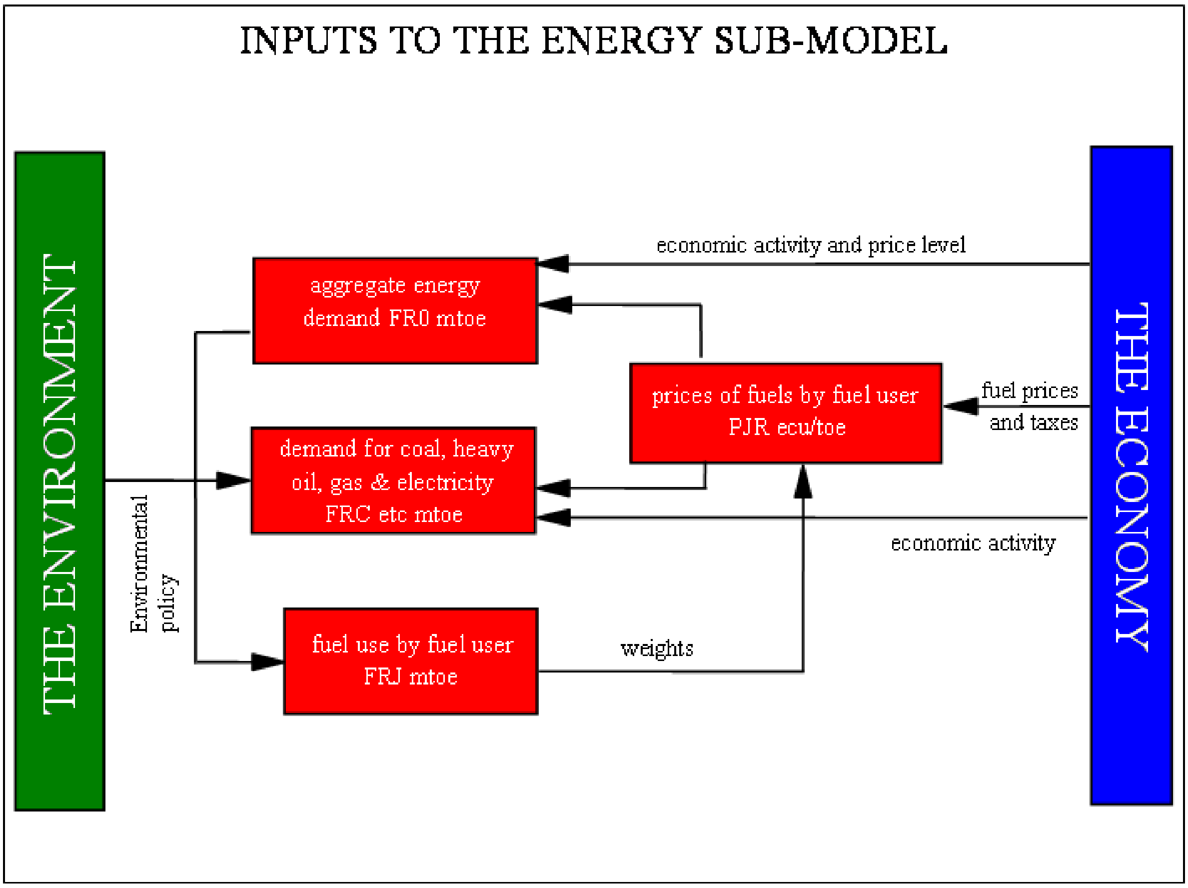
The two approaches also start from different conceptions of the nature of markets. Most top-down models, although not E3ME, do not admit to the possibility of market imperfections (eg imperfect competition). Most importantly, the existence of costless opportunities is often assumed away (except at the margin). Energy consumption (and thus carbon dioxide emissions) are a reflection of revealed preferences and thus any alternative technological scenarios which have not been taken up in the economy are left unexploited for sound economic reasons, such as agent uncertainty (with respect to supply and demand factors) or 'hidden' factors (such as disruption or management costs). Conversely, in bottom-up models the inability of the economy to reach a technologically efficient supply chain in terms of the provision of energy services is attributed to market imperfections (e.g. credit constraints, information asymmetries, transaction costs). The relationship between such imperfections and decision-making is, however, left unexplored.

As noted, both types of analysis possess important strengths, but both have weaknesses when used to address long-term issues. On the one hand in top-down models, the notion that an elasticity of substitution between capital and other factors (estimated on the basis of 30 years of data, or imposed on the basis of intuition or the requirements of functional form) can be used to make useful comments about the world over the next 50 or 100 years from now is suspect. Indeed, beyond a certain number of years it is the engineering characteristics of the 'back-stop' technology, and not the behavioural relations themselves, around which the carbon-energy-output relationship revolves. On the other hand the depiction of the long-run in bottom-up models as a menu of technological options is clearly unsatisfactory as well. At best, the technological options can be presented in chronological form (commercially available, in development stages, technologically feasible), coming on line progressively. By defining capital precisely the models cannot be made dynamic in a satisfactory manner unless the path of technological change is known, and as such are restricted in their relevance to short and medium-term analysis.

In addition, the characteristics of the two approaches limit the relevance of the respective analyses. For instance, top-down models are not able to analyse the effects of non-price based policies which affect the nature of the market itself and not just prices within the market. Institutions and regulations are (implicitly) not subject to change. Given the prevalence of imperfections in the market for energy services, such an omission is significant. Conversely, bottom-up models are not able to analyse the price effects of the introduction of the options enumerated, or associated feedback effects. For instance, an analysis which examines the technological options available to the electricity supply industry misses important feedback effects unless it examines the effects of such a programme on the construction industry which undertakes the conversion, on the energy sector which is faced with significant dislocation, and on those sectors which use electricity and other energy carriers intensively as inputs in production.

E3ME's Top-Down Energy Submodel

The energy submodel in E3ME46 is constructed, estimated and solved for 19 fuel users, 12 energy carriers (termed fuels for convenience below) and the 27 regions of E3ME. The chart Inputs to the energy sub-model shows the inputs from the economy and the environment into the components of the submodel and the chart Feedback from the energy sub-model shows the feedback from the submodel to the rest of the economy.



Aggregate energy demand, shown at the top of the first chart, is determined by a set of co-integrating equations, with the main explanatory variables being:

- Economic activity in each of the 19 fuel users
- Average energy prices by the fuel users relative to the overall price levels
- Technological variables, represented by R&D expenditure in key industries producing energy-using equipment and vehicles.

Fuel use equations are estimated for four fuels - coal, heavy oils, gas and electricity – with four sets of equations estimated for the fuel users in each region. These equations are intended to allow substitution between these energy carriers by users on the basis of relative prices, although overall fuel use and the technological variables are allowed to affect the choice. Since the substitution equations cover only 4 of the 12 fuels, the remaining fuels are determined either as fixed ratios to aggregate energy use or are assumed to behave in an identical way as other, closely related fuels (e.g. other coal and hard coal, crude oil and heavy fuel oil, other gas and natural gas). The final set of fuels used must then be scaled to ensure that it adds up to the aggregate energy demand (for each fuel user and each region).

E3ME's Emission Submodel

The emissions submodel calculates air pollution generated from end-use of different fuels and from primary use of fuels in the energy industries themselves, particularly electricity generation. Provision is made for emissions to the atmosphere of CO_2, SO_2, NO_X, CO, methane (CH_4), Black smoke (PM10), volatile organic compounds (VOC), nuclear, lead, CFCs and the other four greenhouse gases N_2O, HFC, PFC, SF6. This means that, where the data are available, the results will include:

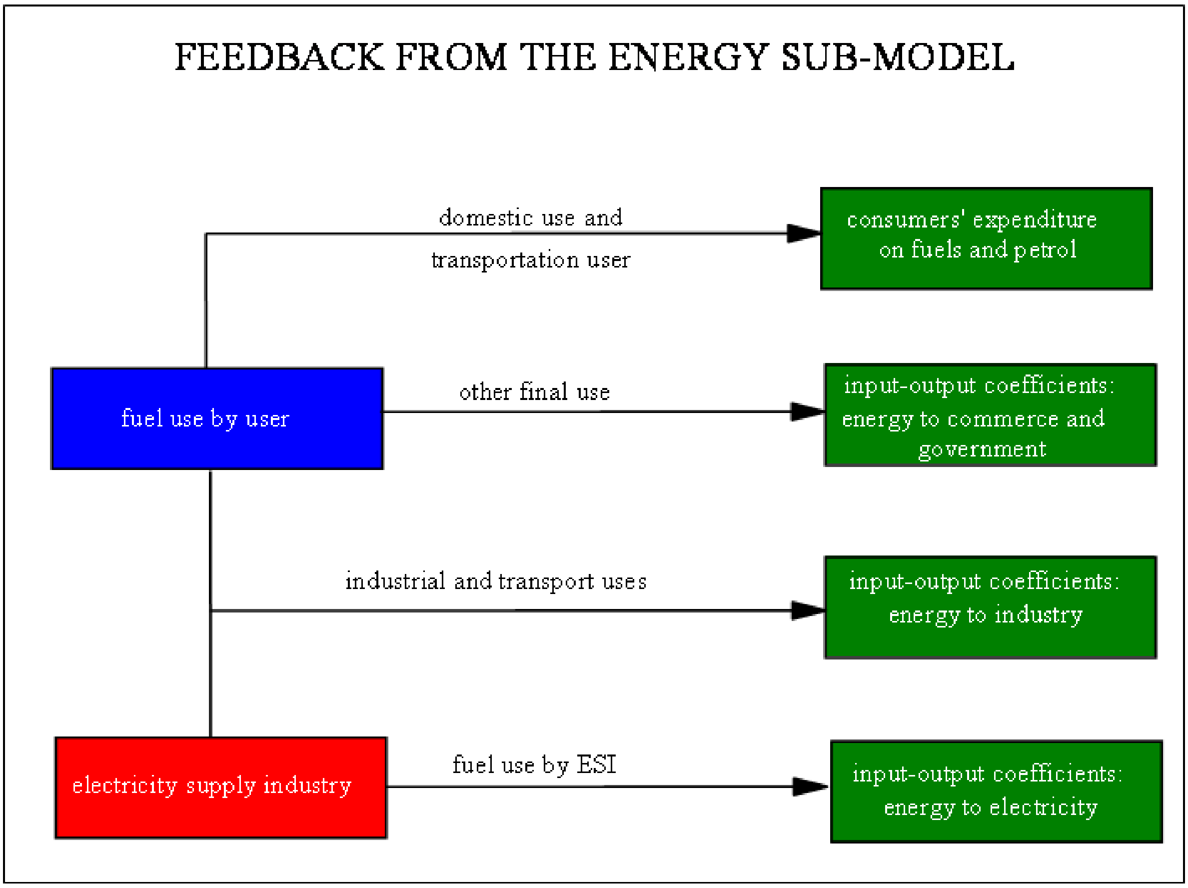
- Effects on non-CO_2 GHGs (especially those in the Kyoto Protocol - CH4, N_2O, HFC, PFC, SF_6)
- Ancillary benefits relating to reduction in associated emissions eg PM_{10}, SO_2, NOx

The theory, data collection and parameter estimates are reported in Working Paper 9b (Bruvoll, Ellingsen and Rosendahl, 1999). This draws from the emission sources (ES) classification which is closely linked to the 19 fuel user groups in E3ME.

Emissions data for CO_2 are available for fuel users of solid fuels, oil products and gas separately. The energy submodel estimates of fuel by fuel user are aggregated into these groups (solid, oil and gas) and emission coefficients (tonnes of carbon in CO_2 emitted per toe) are calculated and stored. The coefficients are calculated for each year when data are available, then used at their last historical values to project future emissions. Other emission data are available at various levels of disaggregation from a number of sources and have been constructed carefully to ensure consistency.

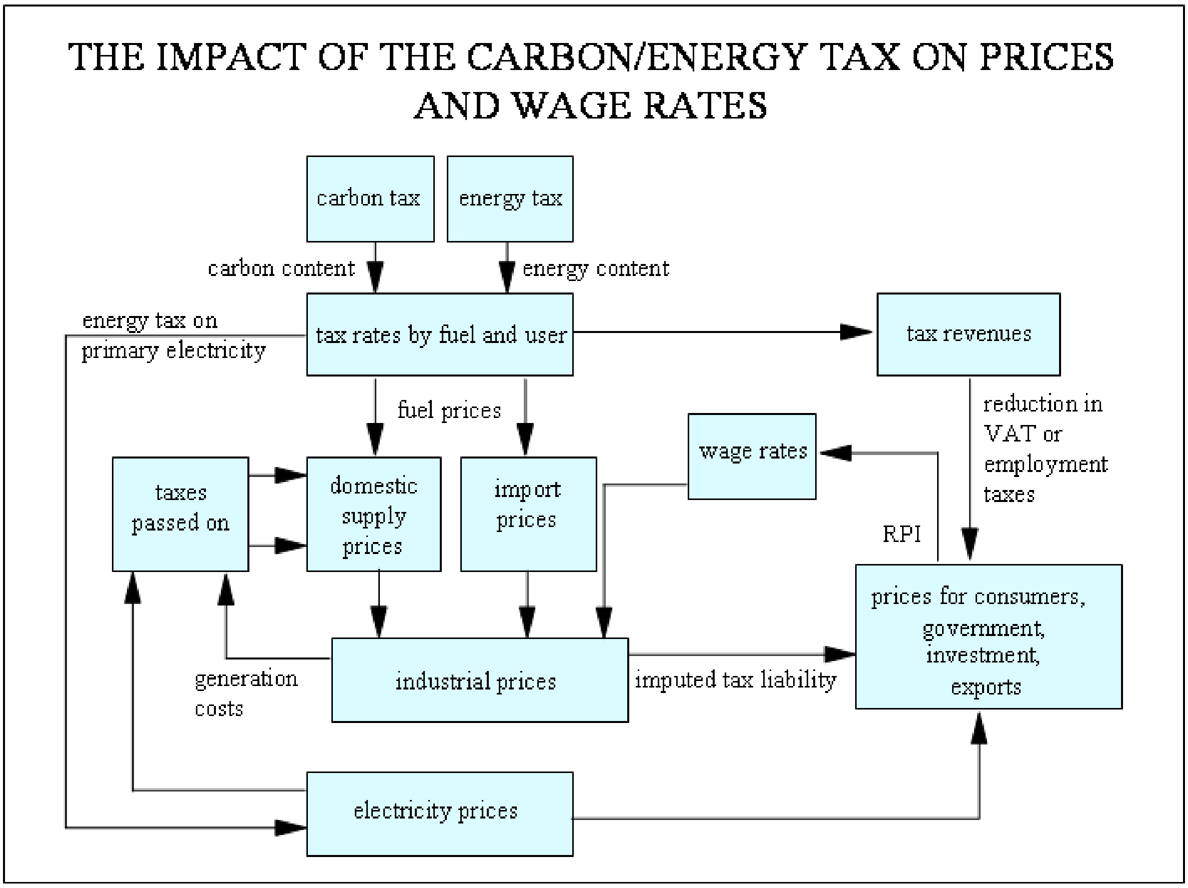
Feedback from E3ME's Energy submodel to the rest of the economy

The chart: Feedback from the energy sub-model shows the main feedbacks from the energy submodel to the rest of the economy. Changes in consumers' expenditures on fuels and petrol can be formed from changes in fuel use estimated in the energy submodel, although the levels are calibrated on historical time-series data. The model software provides an option for choosing either the consumers' expenditure equation solution, or the energy equation solution. Whichever option is chosen, total consumer demand in constant values matches the results of the aggregate consumption function with any residual held in the unallocated category of consumers' expenditure. The other feedbacks all affect industrial, including electricity, demand via changes in the input-output coefficients.



The Effects of a Carbon/Energy Tax in E3ME

One of the purposes of the model is to provide a consistent and coherent treatment of fiscal policy in relation to greenhouse gas emission. Some form of carbon/energy tax is an important component of such policy and E3ME is capable of exploring scenarios involving such a tax, as well as other fiscal and alternative means of reducing emissions. The chart: Impact of the carbon/energy tax on prices and wage rates shows how the tax affects prices and wage rates in the model. There are inevitably certain simplifying assumptions made in modelling a carbon/energy tax.



THE IMPACT OF THE CARBON/ENERGY TAX ON PRICES AND WAGE RATES

The first assumption is that the effects of the tax in the model are derived entirely through the impact of the tax on fuel prices, and through any use of the subsequent revenues from the tax in reducing other taxes. Other effects are not modelled. For example, if the introduction of such a tax caused the electricity industry to scrap coal-burning plant in advance of what might be expected from the relative price change induced by the tax, this effect would have to be imposed on the model results.

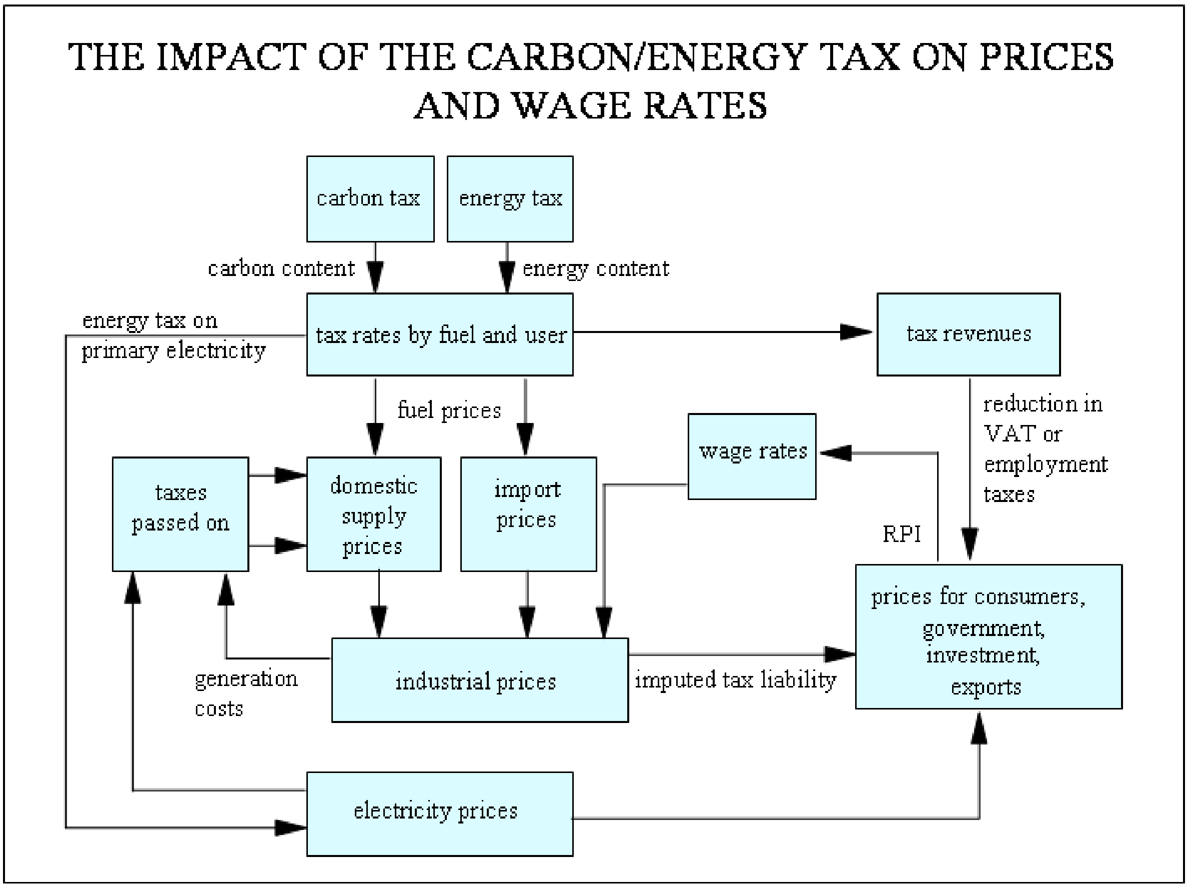
The two components of the tax are treated separately. The carbon component of the tax is given in real prices of the starting year as a rate in euros per tonne carbon (euros/tC) emitted in the form of CO_2. The rate is then indexed on average consumer prices in each of the EU regions to give annual rates over the projection period. The carbon tax liability of all fuels is calculated on the basis of their CO_2 emissions, and converted into euros per tonne oil equivalent (euros/toe) on the basis of the heat content of the fuels. The energy component of the tax is expressed in terms of euros/toe directly and again the escalating rate is indexed to consumer prices in each region. A matrix of total energy tax rates (in euros/toe) in the form of additional excise duties on energy products by fuel user by fuel, can then be constructed for each region in each year. Tax revenues can be calculated from fuel use; the revenues will be reduced according to the fall in use, but will rise according to price inflation and any escalator in the tax rates.

The second assumption is that imports and domestic production of fuels will be taxed according to the carbon and energy content of the fuels, with exports exempt from the tax coverage. The treatment is assumed to correspond to that presently adopted by the authorities for excise duties imposed on hydrocarbon oils. It is assumed that industries and importers pay the tax, and that it is then passed on in the form of higher fuel prices paid by the fuel users. A further assumption is that industrial fuel users pass on all the extra costs implied by the tax in the form of higher prices for goods and services. The increase in final price will be a result of the direct and indirect carbon/energy content of each commodity distinguished in the model.

If the revenues are used to reduce employer tax rates, then industrial employment costs will fall and these reductions in costs are also assumed to be passed on through the industrial system.

The net effect on industrial and import prices will eventually feed through to consumer prices and will affect relative consumption of goods and services depending on the carbon/energy content and on their price elasticities. The higher consumer prices will then lead to higher wage claims. The econometric evidence supports the theoretical presumption that all the tax is eventually paid by the final consumer and this condition is imposed in the long-term solution of the model.

The chart: Impact of the carbon/energy tax on fuel use, CO_2 emissions and industrial employment shows the consequent effects of these price and wage rate changes. The changes in relative fuel prices as a result of the tax will change fuel use, depending on substitution elasticities. The fuel price increases will be passed on to more general increases in prices, which will cause substitution in consumers' expenditure, in exports and between imports and domestic production. These changes will feed back to fuel use. CO_2 emissions are derived directly from the use of different fuels. If employment costs are reduced when tax revenues are recycled, then industrial employment will be stimulated directly, with a further indirect effect as labour-intensive goods and services gain in relative price competitiveness.



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Editor’s Notes

A partnership of nine UK universities developing and transferring knowledge to support aviation sector and Government work to strengthen the sustainability performance of air transport. Omega is working with key players to answer science questions, explore technology and operational solutions and provide wider knowledge that helps the sector make effective environmental decisions. The target is long-term sustainability for air transport to meet the needs of society: some 40 academic studies and other activities will be completed during 2008 to guide future strategy. Omega is led by Manchester Metropolitan University, with Cambridge and Cranfield universities.

www.omega.mmu.ac.uk

Cambridge Centre for Climate Change Mitigation Research (4CMR)

4CMR is an interdisciplinary research centre within the Department of Land Economy at the University of Cambridge.

Our objective is to foresee strategies, policies and processes that are effective in mitigating human-induced climate change. We combine computer modelling with expert knowledge from economics, energy systems, engineering, applied mathematics and environmental science to understand how the transition to a low carbon economy can happen quickly, efficiently and equitably.

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