

CSIM3 MODEL SCENARIOS AND RESULTS OVERVIEW

May 2009



1. Model overview

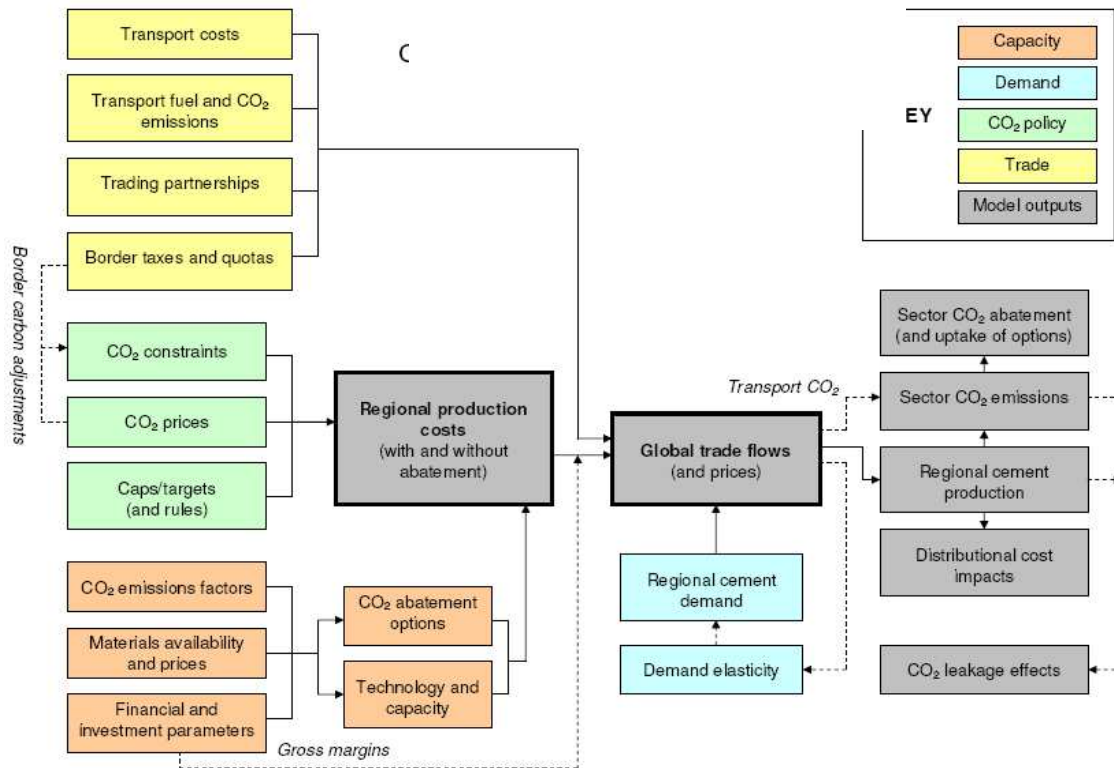
The CSIM3 model has been designed to assess the implications of different carbon constraints introduced post 2012 ('policy scenarios') applied to the cement sector through 2005-2030. The model is a bottom-up economic model based on eight world regions and seeks to meet global and regional demand for cement at least cost. The model determines cement production costs by region over time and resulting international trade flows and regional production volumes.

Key model principles include:

- World cement demand is always met
- Regional cement demand is met at lowest cost, through domestic production and/or imports
- Investment decisions are made in the year when capacity is needed – the model does not look ahead
- Profit maximization behaviour is assumed (as opposed to e.g. market share maximization behaviour)
- Production costs (including increases in costs over time and the cost of CO₂) are fully passed through to the user via the cement price ⁽¹⁾
- The highest marginal cost producer in each region sets the region's cement market price
- Regions seek to meet domestic demand and may then export to other regions where it is profitable to do (subject to cost of production, price in export market, transportation and tax costs, and any defined trade restrictions)
- Only the cement sector is modelled; where carbon prices exist, these are user-defined and the cement sector acts as a price taker. There is always demand at these prices for any carbon allowances/credits sold by the sector.

A schematic flow diagram of the CSIM3 model is shown below, illustrating the key model inputs and outputs.

(1) Note that for regions under absolute emissions caps, the cost of carbon is defined as the annual CO₂ production not covered by freely allocated, or 'grandfathered' allowances (i.e. under full auctioning all CO₂ produced is paid for at the regional carbon price and passed on via the cement price).



Model inputs

Key model data inputs include:

- Technology and capacity details of existing and new cement production facilities by region, over time (energy and electricity use, fuel mix, blending rates, process emissions, phasing out of shaft kilns etc)
- Production and investment cost data, by kiln type and region, over time
- Cement demand by region over time ⁽¹⁾
- Transportation costs by region-region relationship (shipping) and region (road transport)
- Availability and cost of blending materials and fuel/electricity by region over time
- CO₂ emissions factors for fuels, electricity and raw materials
- Availability, costs and technical details of CO₂ abatement options and how they can be applied to existing and new facilities over time and by region (energy efficiency, blending, alternative fuels, carbon capture).

The majority of model data inputs are retained throughout all policy scenarios as ‘key assumptions’. These key assumptions and datasets have been developed through consultation with CSI members and stakeholders and draw on information from various published sources e.g. CSI *Getting the Numbers Right (GNR)* database and CSI Reporting Protocol, IEA data, cement trade and market analysis data, regional academic studies etc. Policy scenarios are developed by introducing various data and assumption changes across regions over time. Any model input data can be changed to define a specific scenario. However, in order to focus on the impacts of different carbon policies being introduced, ‘base’ policy scenarios are defined principally in terms of carbon constraints applied to regions - or groups of regions - over time. A wider range of data changes can then be applied to these base policy scenarios as model sensitivities.

(1) Values for the price-demand elasticity of cement can also be entered (this has been assumed to be zero in the base scenarios)

The key data inputs (or 'scenario assumptions') which define carbon policy scenarios are:

- Type and depth of commitments (i.e. absolute CO₂ caps or emissions efficiency goals, and their stringency)
- Regional CO₂ prices (defining the price at which carbon is traded in capped regions or credited/sanctioned in emissions efficiency goals regions) by region, over time
- Availability of CO₂ abatement options available to the cement sector by region, over time

These scenario assumptions are presented in more detail in the next section (2: *Policy scenarios*).

Model outputs

The CSIM3 model is able to produce a wide range of model 'reports' for each defined policy scenario for chosen years through 2030. Key model outputs by scenario include:

- Cement sector CO₂ emissions - MtCO₂ (world and by region) ⁽¹⁾
- AF and blending uptake - % (*world average and by region*)
- CO₂ intensity - tCO₂/t cement (*world average and by region*)
- Global trade flows - Mt cement (*net cement imports by region*)
- Cost, price and revenue data, including net carbon costs/revenues (*world and by region*)

The following key outputs can then be assessed for scenarios *with reference to a chosen baseline*

- Cement sector CO₂ emissions reduction (*world, across scenarios*)
- Trade and CO₂ leakage effects - % rate (between region groups, against a defined baseline) ⁽²⁾
- Change in gross profit margin - % (by region, or groups of regions i.e. Annex I and non-Annex I)

2. Policy scenarios

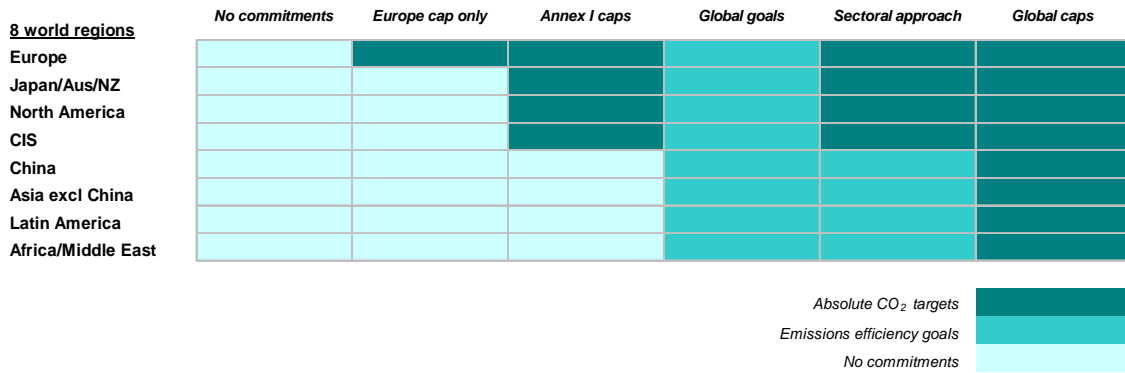
Overview

The chosen policy scenarios have been defined, and can be understood, principally in terms of the type of CO₂ commitment made by each region's cement sector. This is shown below. The 'Sectoral approach' defined here is a mix of absolute caps in Annex I countries and emissions efficiency goals in non-Annex I countries. Many other policy combinations are possible within a sectoral approach - the key is a set of policies which will drive mitigation actions.

(1) CO₂ emissions are reported as direct emissions (i.e. fuel combustion and process emissions). Similarly, absolute caps and emissions efficiency goals are based on direct CO₂ emissions; it is assumed that emissions from electricity would be capped (or covered) via a power sector allocation (or sector target). For reasons of consistency this scope of emissions reporting and accounting has been used throughout the project.

(2). Different definitions of CO₂ leakage exist in the literature. UNFCCC (e.g. IPCC WGIII) and IEA literature suggests that leakage for a sector can be defined as the increase in CO₂ emissions outside a region implementing a carbon policy divided by the decrease in CO₂ emissions in the region implementing the policy. According to the IEA (*Competitiveness and Carbon Leakage - Focus on Heavy Industry*, IEA 2008) the reduction in emissions in the implanting region may comprise abated emissions (intended effect) as well as emissions reductions due to loss of market share (unintended effect). Other sources focus on 'competitiveness driven carbon leakage' only. The most commonly used UNFCCC/IEA definition is used for the purposes of this project.

Scope of international commitment post Kyoto



The scenarios shown represent a concise but broad-ranging set of possible future policy commitments based on mixes of absolute caps and emissions efficiency goals across the eight world regions. Policy changes between these scenarios are defined such that they *only occur post-Kyoto* (i.e. from the start of 2013 onwards). Although commitment types can be applied to any combination of regions, several of the scenarios define commitment types according to UNFCCC Annex I and non-Annex I regional groupings. Certain model results can therefore be presented in terms of net, or aggregated, impacts upon Annex I and non-Annex I regions.

Three commitment periods are defined across which commitments can be applied to regions - 2005-2012; 2013-2020; and 2021-2030. Although the CSIM3 model produces detailed results outputs for all years from 2005 to 2030, key summary reports are produced for the years 2005, 2012, 2020 and 2030 (i.e. in the base year and then in the year at the end of each commitment period).

The following base policy scenarios have been chosen:

1	No commitments	No carbon prices or cement sector commitments post-Kyoto
2	Europe cap only	Only Europe adopts commitment post-Kyoto - cement sector emissions are capped
3	Annex I caps	All Annex I regions (Regions 1-4) adopt absolute caps post-Kyoto
4	Global goals	Cement sector in all world regions adopts emissions efficiency goals (with credits & sanctions)
5	Sectoral approach	Annex I caps and emissions efficiency goals (with credits & sanctions) in non-Annex I regions
6	Global caps	Cement sector in all world regions adopts absolute caps post-Kyoto

Policy scenario assumptions

The three tables below summarise (for each region across each policy scenario and commitment period):

1. Regional CO₂ prices (i.e. allowance prices in capped regions; credit/sanction prices in emissions efficiency goals regions)
2. Absolute caps / emissions efficiency goals (% reductions over period against defined base years / baselines)
3. Abatement option parameters (maximum % application of technology options, as defined in the table notes)

1. Regional carbon prices (\$/tCO₂)

	No commitments			Europe cap only			Annex I Caps			Global goals			Sectoral approach			Global caps		
	2005-2012	2013-2020	2021-2030	2005-2012	2013-2020	2021-2030	2005-2012	2013-2020	2021-2030	2005-2012	2013-2020	2021-2030	2005-2012	2013-2020	2021-2030	2005-2012	2013-2020	2021-2030
Europe	50	0	0	50	100	150	50	100	150	50	50	75	50	100	150	50	100	150
Japan/Aus/NZ	0	0	0	0	0	0	0	100	150	0	50	75	0	100	150	0	100	150
North America	0	0	0	0	0	0	0	100	150	0	50	75	0	100	150	0	100	150
CIS	0	0	0	0	0	0	0	100	150	0	50	75	0	100	150	0	100	150
China	0	0	0	0	0	0	0	0	0	0	50	75	0	50	75	0	100	150
Asia excl China	0	0	0	0	0	0	0	0	0	0	50	75	0	50	75	0	100	150
Latin America	0	0	0	0	0	0	0	0	0	0	50	75	0	50	75	0	100	150
Africa/Middle East	0	0	0	0	0	0	0	0	0	0	50	75	0	50	75	0	100	150

Notes:

Where absolute CO₂ caps apply, any trading (shortfall/surplus) is undertaken at these prices

Cap allocation by auction (i.e. non-free allocation) assumes allowances are auctioned these prices

Where emissions efficiency goals apply sanctions for not meeting goals, these are set at these price levels

Absolute CO₂ targets

Emissions efficiency goals

No commitments

2. Cement sector caps/emissions efficiency goals (% reduction)

	No commitments			Europe cap only			Annex I Caps			Global goals			Sectoral approach			Global caps		
	2005-2012	2013-2020	2021-2030	2005-2012	2013-2020	2021-2030	2005-2012	2013-2020	2021-2030	2005-2012	2013-2020	2021-2030	2005-2012	2013-2020	2021-2030	2005-2012	2013-2020	2021-2030
Europe	-8%			-8%	-20%	-20%	-8%	-20%	-30%	-8%	-10%	-20%	-8%	-20%	-30%	-8%	-20%	-30%
Japan/Aus/NZ								-10%	-15%		-10%	-20%		-10%	-15%		-10%	-15%
North America								-10%	-15%		-10%	-20%		-10%	-15%		-10%	-15%
CIS								0%	0%		-10%	-20%		0%	0%		0%	0%
China											-10%	-20%		-10%	-20%		0%	0%
Asia excl China											-10%	-20%		-10%	-20%		0%	0%
Latin America											-10%	-20%		-10%	-20%		0%	0%
Africa/Middle East											-10%	-20%		-10%	-20%		0%	0%

Notes:

Values shown are absolute caps and emissions efficiency goals (depending on box colour) for the cement sector

Absolute cap for Europe 2005-2012 reflects EUETS and mirrors Kyoto agreements

Annex I region absolute caps use 1990 baseline; other regions' absolute caps use 2005 baseline

Emissions efficiency goals are all tCO₂/t cement and indicate % target reduction from baseline in final year of period

Absolute CO₂ targets

Emissions efficiency goals

No commitments

3. Abatement option deployment rates

	No commitments			Europe cap only			Annex I Caps			Global goals			Sectoral approach			Global caps		
	CCS	AF	Blend	CCS	AF	Blend	CCS	AF	Blend	CCS	AF	Blend	CCS	AF	Blend	CCS	AF	Blend
Europe	30%	-	-	30%	60%	100%	30%	60%	100%	30%	40%	60%	30%	60%	100%	30%	60%	100%
Japan/Aus/NZ	30%	-	-	30%	-	-	30%	60%	100%	30%	40%	60%	30%	60%	100%	30%	60%	100%
North America	30%	-	-	30%	-	-	30%	60%	100%	30%	40%	60%	30%	60%	100%	30%	60%	100%
CIS	30%	-	-	30%	-	-	30%	60%	100%	30%	40%	60%	30%	60%	100%	30%	60%	100%
China	30%	-	-	30%	-	-	30%	-	-	30%	40%	60%	30%	40%	60%	30%	60%	100%
Asia excl China	30%	-	-	30%	-	-	30%	-	-	30%	40%	60%	30%	40%	60%	30%	60%	100%
Latin America	30%	-	-	30%	-	-	30%	-	-	30%	40%	60%	30%	40%	60%	30%	60%	100%
Africa/Middle East	30%	-	-	30%	-	-	30%	-	-	30%	40%	60%	30%	40%	60%	30%	60%	100%

Notes:

Values shown are max possible deployment % for the relevant abatement option

(these define the max availability for each option as defined in the model S-curves)

Max usage for AF (alternative fuels): 90% of fuel mix in dry kilns and 20% in wet/shaft

Max blending rate: 50% of cement for all regions; uptake limited by regional availability

CCS (post combustion carbon capture & storage) is available for dry kiln new build and retrofit from 2016

Energy efficiency measures on existing plant is available from 2005; potential varies according to regional average GJ/t clinker rate

High AF and blending uptake

Medium AF and blending uptake

Hold AF and blending at 2005 % levels

Choice of baseline

As described earlier under *Model outputs*, in order to assess certain results and trends arising from the introduction of carbon policies, a baseline scenario is required. The 'No commitments' scenario represents a projection of cement production, trade flows and CO₂ emissions occurring in the absence of any commitments or CO₂ prices post-Kyoto. The development of cement prices and trade flows therefore occurs independently of differential carbon constraints such that there is a competitive 'level playing field' between regions in respect of carbon constraints, whilst the evolution of absolute sector CO₂ emissions and CO₂ emissions efficiency reflects a 'business as usual' turnover of cement plant technology as new efficient kiln is introduced to meet rising demand and other kiln types (i.e. shaft kiln) are retired over time.

Therefore, the 'No commitments' scenario has been chosen against which the full range of potential impacts arising from the chosen policy scenarios can be illustrated. It is important to note the 'No commitments' baseline is not intended to represent the 'most likely' policy future.

Allocation of allowances in capped regions

For those scenarios in which certain regions or groups of regions adopt absolute caps post-Kyoto, the choice of allowance allocation methodology (i.e. free allocation or auctioning) is important to the results produced. This is because a region's carbon cost of cement production is determined by the share of annual CO₂ produced *not covered* by freely allocated, or 'grandfathered', allowances. Where allowances are freely allocated, three cases can be considered to illustrate this factor:

Case A: *Where a region produces CO₂ exactly equal to its free allocation in a given year, there is no carbon cost*

Case B: *Where a region produces CO₂ greater than its free allocation in a given year, there is a carbon cost i.e. the shortfall must be met by buying the required volume of allowances at the regional carbon price*

Case C: *Where a region produces CO₂ less than its free allocation in a given year, there is a carbon benefit i.e. the surplus can be traded at the regional carbon price*

With full auctioning, every tonne of CO₂ produced represents a cost. A mixture of free allocation and auctioning can also be simulated, in which case the cost will now also be determined by the share of auctioning chosen (as well as the actual CO₂ produced, the carbon price and the carbon intensity of production). The carbon cost is then passed on to the end-user via an increase in the regional cement price, which in turn may change international cement trade flows. For example, in the case of full auctioning a region directly pays for all of its CO₂ production with the potential effect of significantly raising the domestic cement price and encouraging significant imports from regions with lower production costs.

Note that border carbon adjustments, or BCAs, could be applied to cement imports from non-capped regions with the intention of offsetting any potential loss of competitiveness (due to increased imports from non-capped regions and/or relocation of cement production to non-capped regions arising from uneven carbon constraints). Their use is explored in more detail later.

Free allocation has been assumed as the allowance allocation methodology for all capped regions in the base policy scenarios.

Emissions efficiency goals

Two of the base policy scenarios apply emissions efficiency goals to regions (i.e. 'Sectoral approach' and 'Global goals'). Where emissions efficiency goals (i.e. carbon intensity) are applied the model proposes a baseline and crediting mechanism, whereby credits are earned only when a region meets - and surpasses - its goal in a given year. Similarly, sanctions are applied when a region does not meet its goal (i.e. it falls short of the goal). The credits earned, or sanctions paid, are then determined by the excess or shortfall multiplied by the regional CO₂ price in the given year, which in this case is the price at which the credits can be sold.

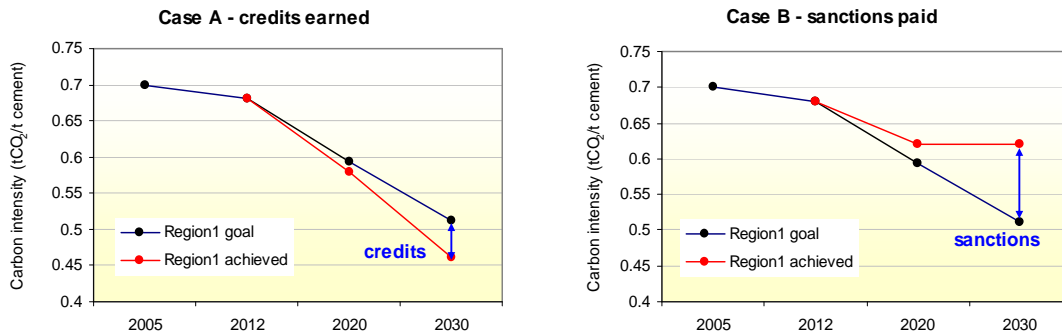
As with allowances traded in capped regions, it is assumed that there is demand for such credits and that their cash value is retained by (or fully recycled back to) the cement sector. As with capped regions, the cement sector in efficiency-based regions is assumed to abate up to the regional CO₂ price i.e. where the cost of abatement is less than the abated cost of production including CO₂ such abatement options will be implemented. This is because, where sanctions and credits apply, every tCO₂ abated represents either a sanction avoided or a credit earned (similarly, every tCO₂ produced represents either a sanction paid or a credit forsaken). The institutional and/or implementation details of such a scheme have not been explored within the scope of this project. However, a key assumption is that supporting policies and measures are implemented in regions that adopt efficiency-based goals.

To ensure that goals set are 'additional' to that which would have occurred in the absence of any commitments, the development of a CO₂ intensity baseline for each region over time is required against which goals are then defined. For each region, the 'No commitments' baseline (e.g. reflecting the introduction of new build kilns and the phasing out of existing kiln over time) is known in terms of tCO₂/t cement produced. Against this baseline, goals can be defined for each region over commitment periods. This is described further below.

The figures below illustrate two cases:

Case A: Region 1 meets its goal and earns credits (equal to CO₂ production x improvement over goal x CO₂ price)

Case B: Region 1 fails to meet its goal and pays sanctions (equal to CO₂ production x shortfall under goal x CO₂ price)



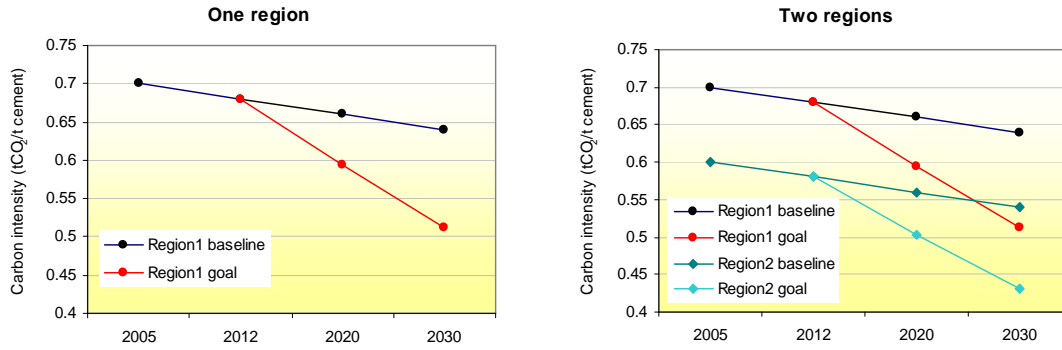
Note that in the case of a 'no lose' approach to sectoral crediting, only Case A applies i.e. where a region meets its goal credits are earned but where it fails to meet its goal, no sanctions are paid. The proposal of a 'no lose' approach raises a problem in that without the threat of sanctions, regions (or companies) would only abate where it was known in advance that credit revenues would exceed abatement costs. This calculation would be highly complex and involve perfect information of a region's future abatement potential and ability to meet its goal and future market carbon prices. Furthermore, companies would likely be incentivised to 'free ride' on the efforts of other companies within the region rather than risk economic loss.

With such inherent risk and economic uncertainty, it is likely that little or no investment in abatement would occur. If sanctions did exist, every tCO₂ abated would then represent a credit earned or a sanction avoided, thereby incentivising abatement and reducing uncertainty of outcomes. In the choice of base policy scenarios involving the use of emissions efficiency goals, the use of credits and sanctions is assumed.

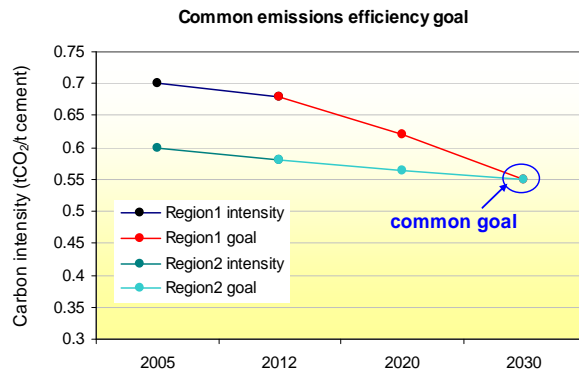
Emissions efficiency goals can be developed in several ways.

Firstly, the scope of goals can take various forms - different goals can be set for (a) existing plant and (b) new build plant; similarly, different goals can be set for different kiln types. For simplicity and equality of comparison with capped regions, goals are proposed at a regional cement-sector wide level (i.e. applying to all cement production) on the basis of direct plant CO₂ emissions only.

Secondly, the manner in which goal levels are set can take various forms. The figures below show a *common reduction rate* approach for (a) one region and (b) more than one region. In these cases, goals are set at a reduction rate (%) in each commitment period against the baseline CO₂ intensity for each region. In the examples shown, regions adopt a 2020 goal of -10% against the baseline 2020 value and a 2030 goal of -20% against the baseline 2030 value. In this way, each region has a different end goal value but a *common reduction rate*.



An alternative approach to that shown above is to set a *common goal* for a future point in time. This is shown below. It can be seen that at the point at which regions enter into the first commitment period (start of year 2013) each region's intensity value is different; the goals are then developed for each region as a linear projection towards a common end goal in 2030. This approach has the effect of requiring relatively greater reduction rates from those regions starting in 2013 with relatively high carbon intensity values; similarly those regions starting in 2013 with relatively low carbon intensity values now experience a less stringent reduction rate.



Within this approach, as with the common reduction rates model described above, the common goal is defined against the 'No commitments' baseline such that the 2030 goal value is set at 20% below the 2030 baseline world intensity value. Depending on the relative weightings of cement production in each efficiency-based goal regions, such a goal may be more or less stringent at a cumulative level than with *common reduction rates* applied. A further design option within a *common goal* approach is to develop more than one goal e.g. one goal for Annex I regions and another for non-Annex I regions.

Other approaches to the development of goals are possible. For example, a bottom-up differentiated approach in which each region negotiates its own goal can be developed. The most likely basis for such a process would be a detailed evaluation of each region's specific circumstances including its cement sector CO₂ abatement potential. However, whilst there will necessarily be technical limits to a region's abatement potential (e.g. availability of blending materials, physical limits to regional CO₂ storage etc), such an assessment is conditional on the price for which credits can be sold - at higher prices, more abatement is economically possible. Such an approach is therefore highly complex and difficult to model quantitatively in a transparent and robust way. It should be noted finally that aspects of each of the possible approaches described above could in theory be combined in a wide range of ways.

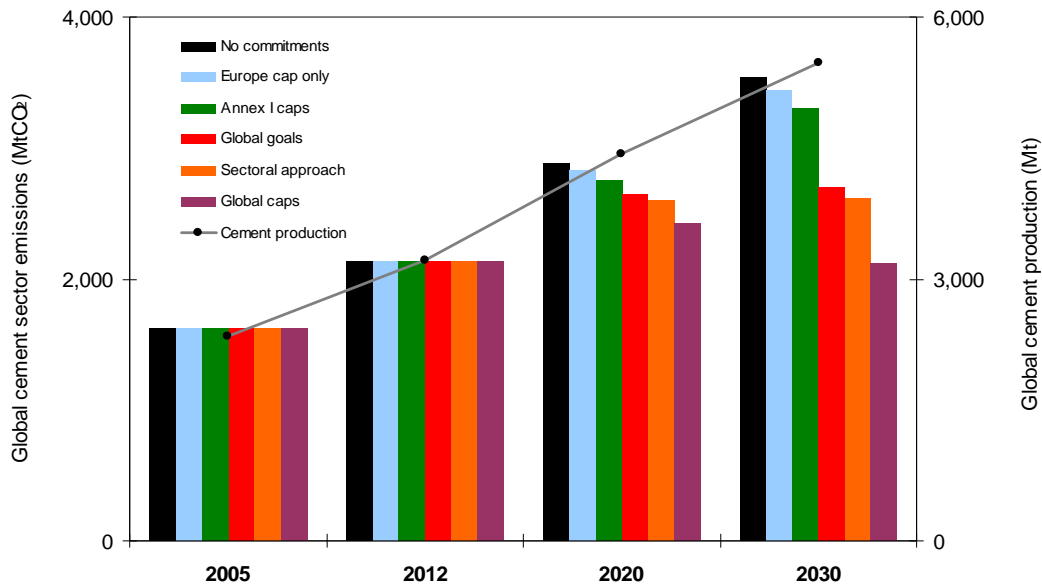
For those base policy scenarios in which efficiency-based goals are assessed ('Global goals and 'Sectoral approach'), a *common reduction rate* approach has been assumed according to the factors described above.

3. Model Results

CO₂ emissions and abatement outputs

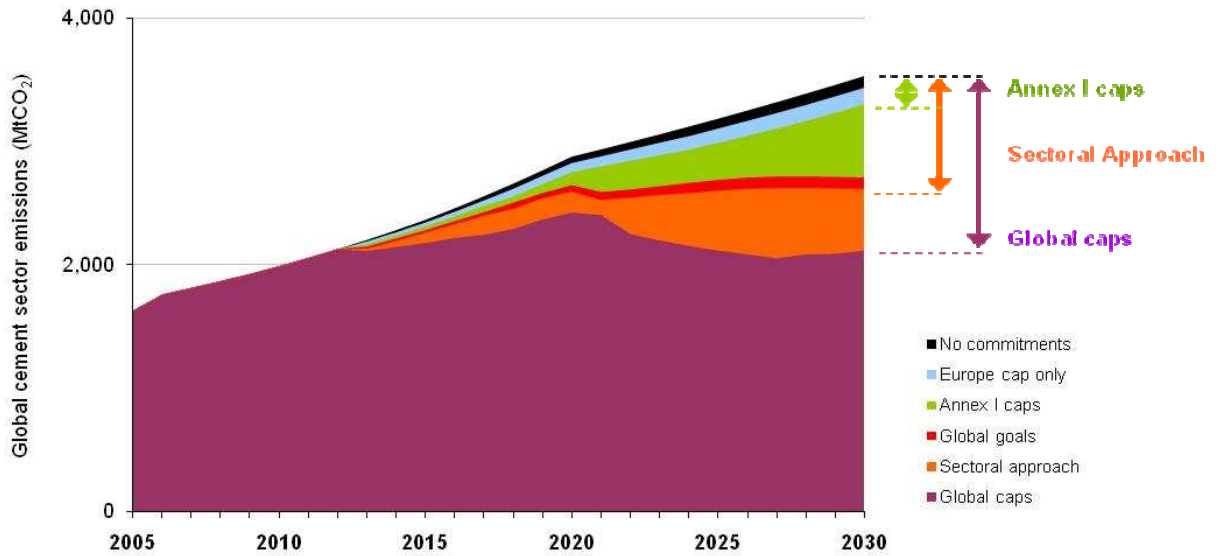
Global cement sector emissions

The graph and table below show world cement sector emissions projections (plotted against cement production) over the forecast period for the range of chosen base policy scenarios.



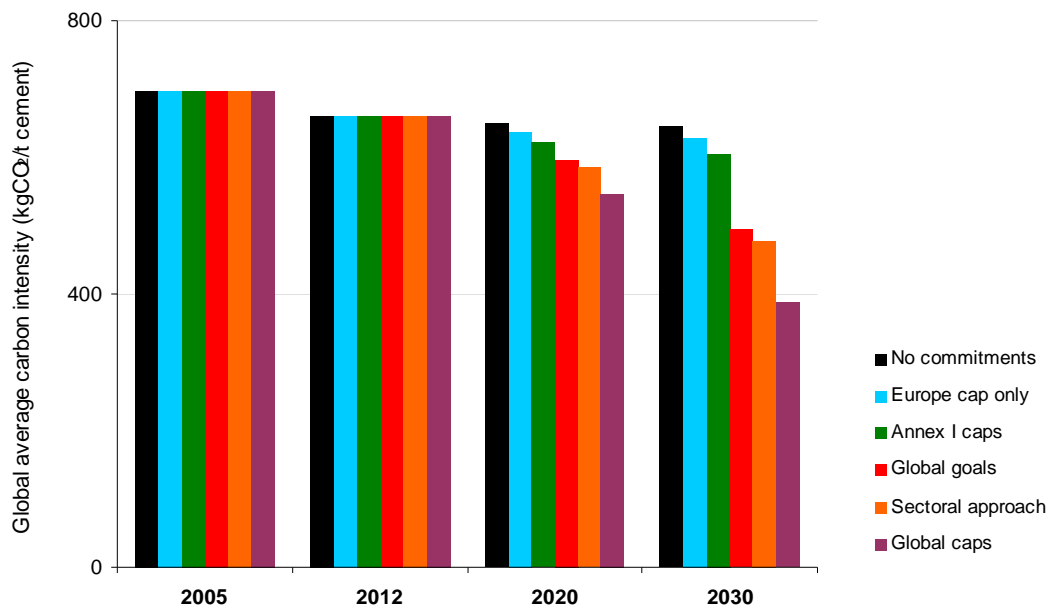
It can be seen that in all cases, absolute emissions increase over time. The greatest reductions - compared to the 'No commitments' baseline - occur in those scenarios in which non-Annex I regions as well as Annex I regions adopt carbon commitments (i.e. 'Global goals', 'Sectoral approach' and 'Global caps'), reflecting the fact that these regions represent the largest, and fastest growing, share of world cement production and sector emissions.

The graph overleaf shows world sector emissions as a continuous time series for each of the base policy scenarios. It can be seen that emissions pathways diverge after 2012 as the various policy options are modelled. Under the 'Global caps' scenario emissions decrease slightly across the final commitment period (2021-2030) and result in a 40% reduction against the baseline by the year 2030. The slight rise in emissions shown over the last few years reflects the fact that the abatement achieved is becoming offset by emissions increases overall (due to a combined effect of increasing cement production and the limits of abatement). All other policy scenarios result in an increase in emissions across successive periods. 'Sectoral approach' indicates a 26% reduction against the baseline by the year 2030 and 'Annex I caps' a 6% reduction.



Global average cement sector emissions intensity

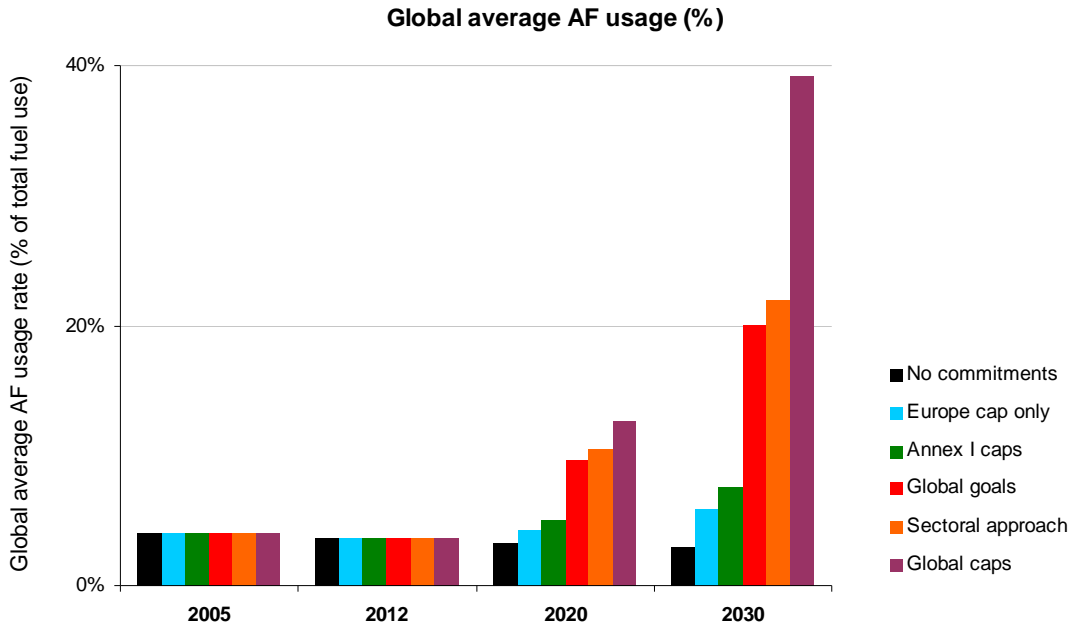
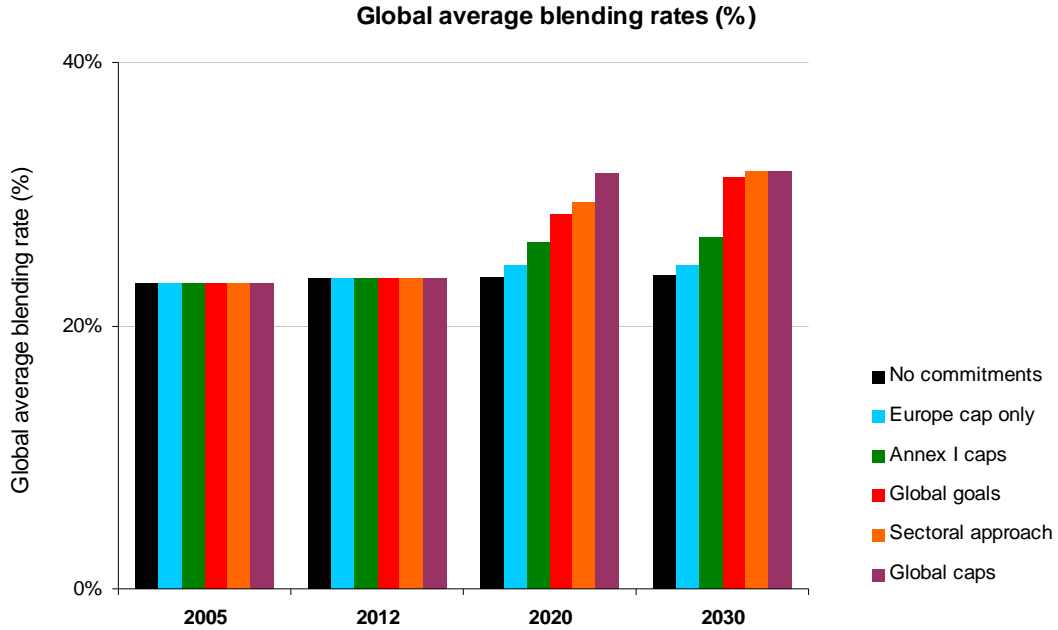
The graph and table below show the corresponding emissions intensity value (kgCO₂/t cement produced). It can be seen that the world average intensity decreases marginally over time in the 'No commitments' baseline mainly reflecting the progressive introduction of new more efficient plant. As with the results for absolute emissions, the observed decrease in intensity over time is most marked under the 'Global goals', 'Sectoral approach' and 'Global caps' policy scenarios.



Global blending rates and alternative fuel usage

The two graphs presented below show world average blending rates and alternative fuel (AF) usage rates across the same range of policy scenarios. The results illustrate that both blending and AF

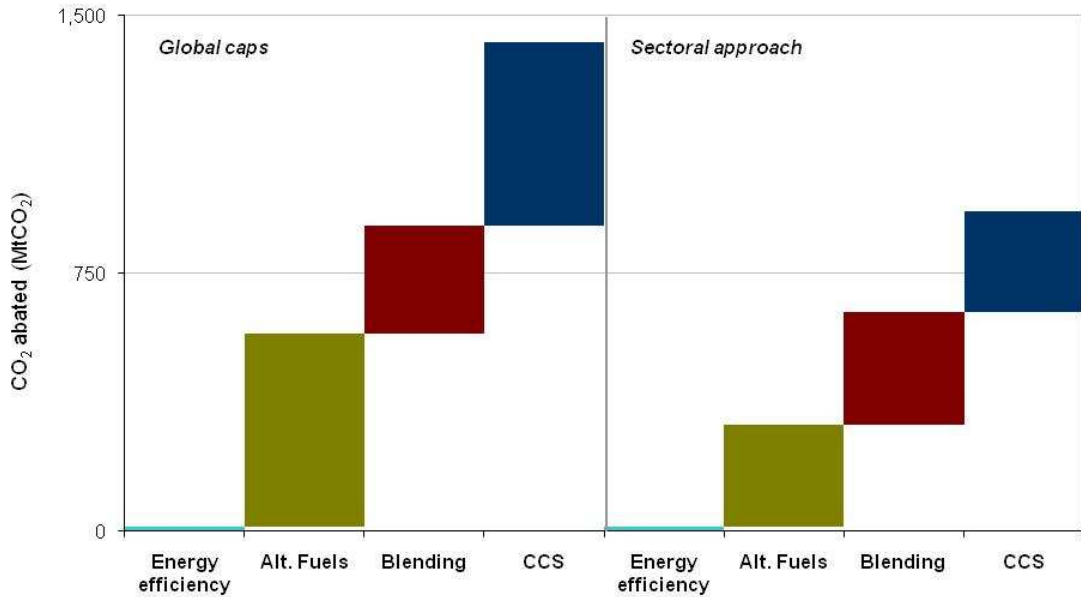
usage rates increase under progressively 'stringent' policy scenarios. However, at a *global* level, it can be seen that there is little difference between the future blending rates results shown under 'Sectoral Approaches' and 'Global caps' reflecting that in some regions in later years, the limits of blending materials available to the cement sector have been reached under the 'Sectoral Approaches' scenario.



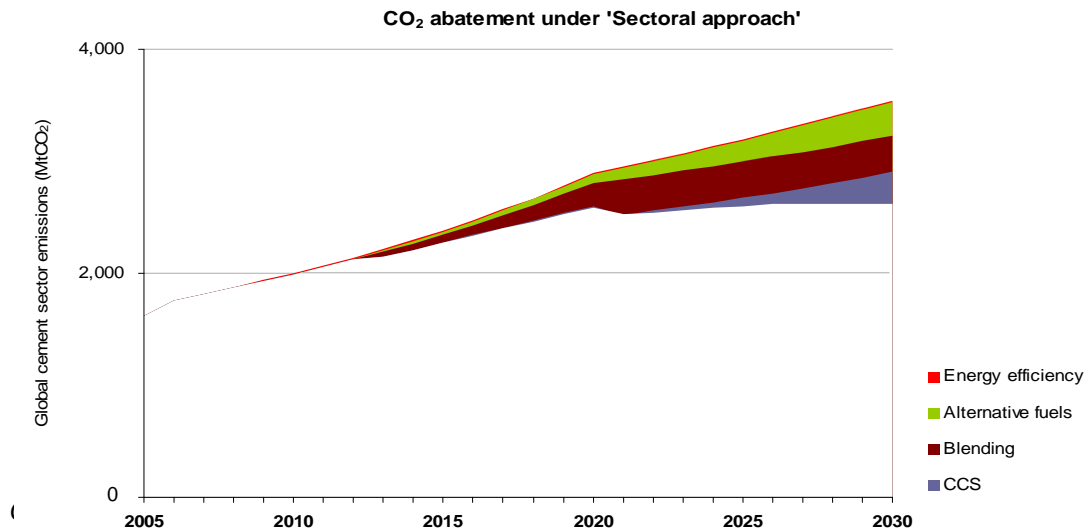
Abatement options used

The graph below provides a breakdown of the abatement options undertaken by the cement sector under the 'Global caps' and 'Sectoral approach' scenarios in 2030. The figures shown indicate global abatement *relative* to the 'No commitments' baseline. It can be seen that while increased blending and AF usage contribute to greater levels of abatement under 'Global Caps' when compared to the

'Sectoral Approach' scenario, the greatest contributor is CCS. The difference is largely driven by the fact that under 'Global Caps' the higher CO₂ price in non-Annex I regions (compared to the price under 'Sectoral Approach' for non-Annex I regions) incentivizes greater levels of CCS deployment. Energy efficiency measures account for a small share of overall abatement; this is because the bulk of energy gains associated with e.g. new kiln penetration and the phasing out of older less efficient plant are accounted for in the baseline ⁽¹⁾.



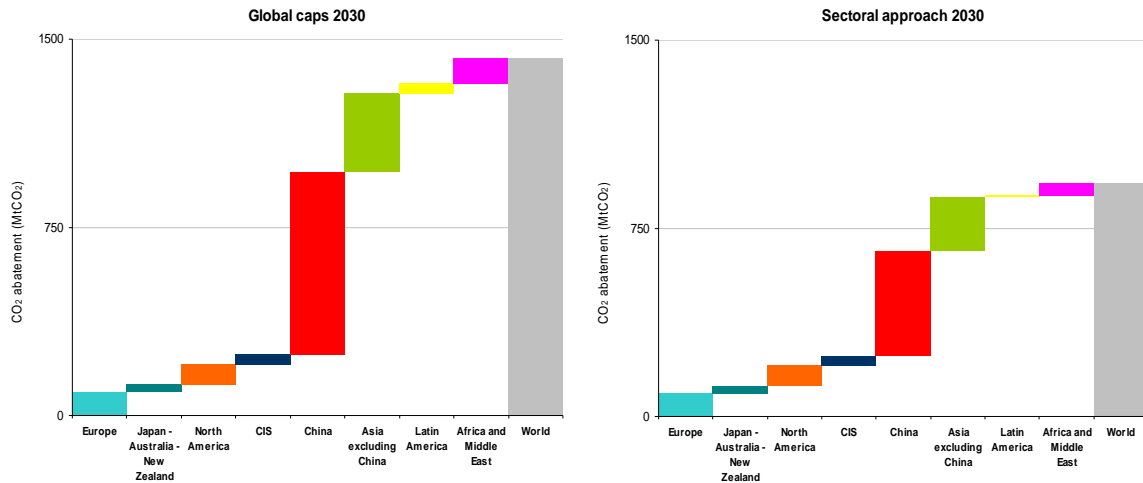
The contribution of each abatement option to global sector abatement over time is illustrated, shown below for the 'Sectoral approach' scenario, in which the contribution of CCS from around 2020 onwards can clearly be seen.



The two graphs shown below provide a summary breakdown of CO₂ abatement by region (against the 'No Commitments' baseline) for the same two policy scenarios in the year 2030. Note that in order to eliminate the effects of trade (in which a region's abatement may be offset by increased production for export purposes) and produce a fair comparison of regional abatement potential, these results have

(1) In addition, potential indirect CO₂ emissions savings arising from the use of Combined Heat and Power (CHP) and other measures are not assessed

been produced with trade disabled in the model. It can be seen that in both cases, China and Asia account for well over half of global sector CO₂ abatement by 2030.

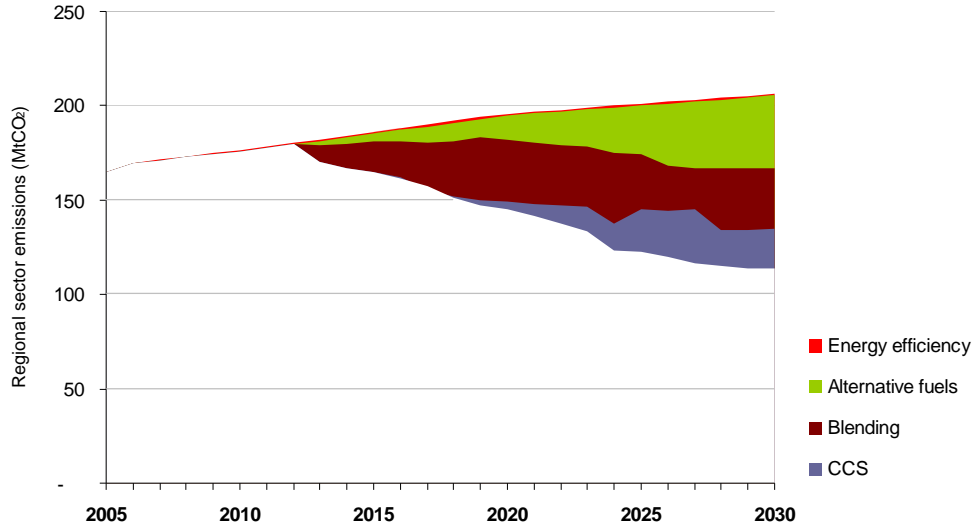


The graphs on the following two pages show a breakdown of abatement options, or abatement ‘wedges’ used over time for each of the eight world regions. As with the graphs shown above, these illustrate the levels of CO₂ abatement attributed to each of the four abatement options over and above that achieved under the ‘No commitments’ baseline. The graphs shown are the results produced under the ‘Global caps’ scenario. Because under this policy scenario the choice of regional CO₂ prices is sufficient to incentivise all abatement lever considered, the graphs can be viewed as a reflection of the total CO₂ abatement potential for each region.

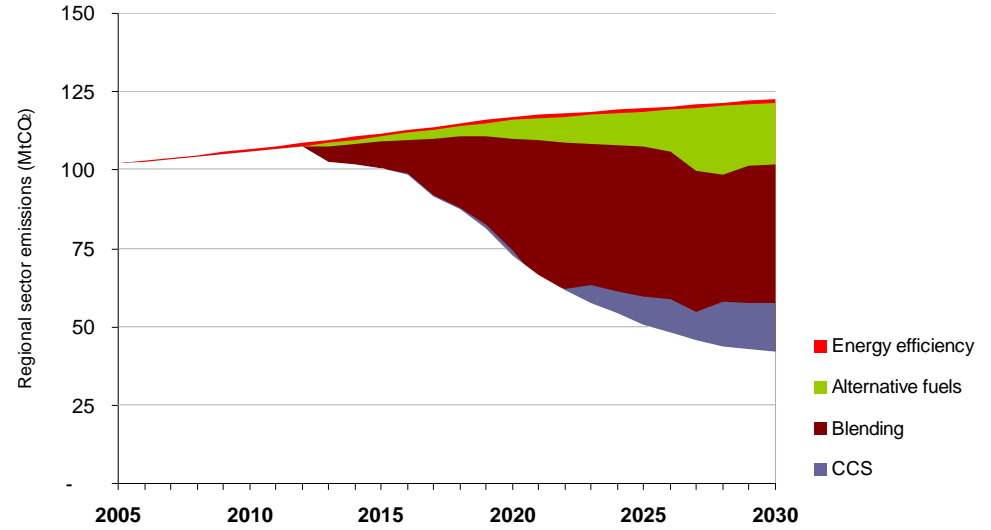
The eight graphs show that each region has significant CO₂ abatement potential. However, it can clearly be seen that the absolute and relative potential from each of the abatement options varies considerably by region. Most noticeably, the abatement potential from blending is seen to vary considerably, reflecting the fact that the cement sector in Annex I regions is understood to have relatively greater access to blending materials than non-annex I regions. The potential from blending is seen to be most limited in the Latin America and Africa + Middle East regions, in part reflecting limited supplies of fly ash and slag from coal power generation and the steel sector relative to other regions. In contrast, the CIS and North America regions are seen to have high abatement potential from blending due to a relatively higher supply of these blending materials over time. Note however that the abatement potential from CCS and alternative fuels is noticeably low in the CIS region; this reflects the dominance of (existing) wet kiln capacity in that region, for which alternative fuel combustion and CCS application are limited.

It should be noted that the levels of abatement attributed to blending and alternative fuels shown in the graphs are also influenced by the blending and alternative fuels rates in the baseline. For example, China has a relatively high level of blending in the baseline whereas North America has a lower level of blending (reflecting current blending levels for both regions). Because blending materials and alternative fuels are finite, their existing and projected use in the baseline will necessarily determine their relative abatement potential within each policy scenario. Another important factor limiting the abatement potential from blending and alternative fuels use is that some regions are forecast to have faster cement demand growth than others; this further serves to make the finite nature of blending materials and alternative fuels more critical (i.e. limited).

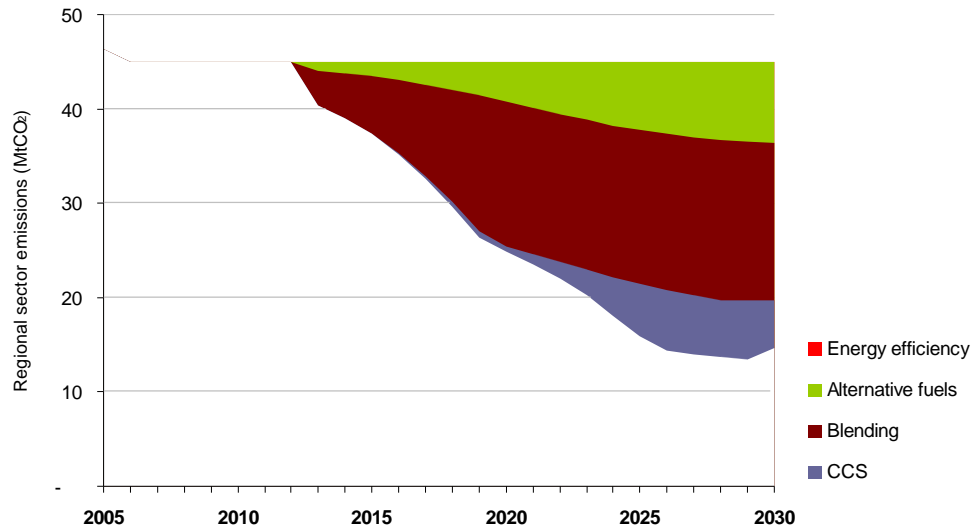
'Global caps': Europe



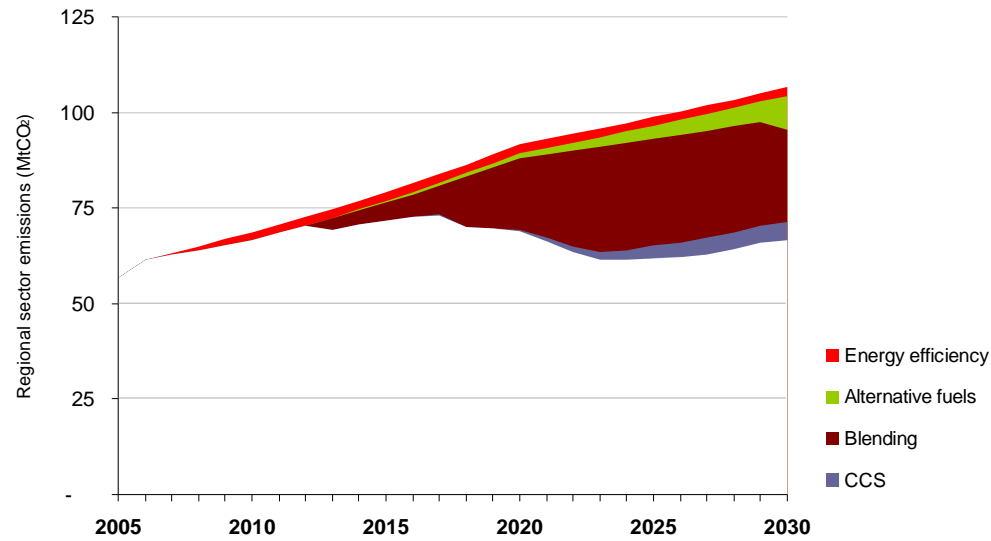
'Global caps': North America

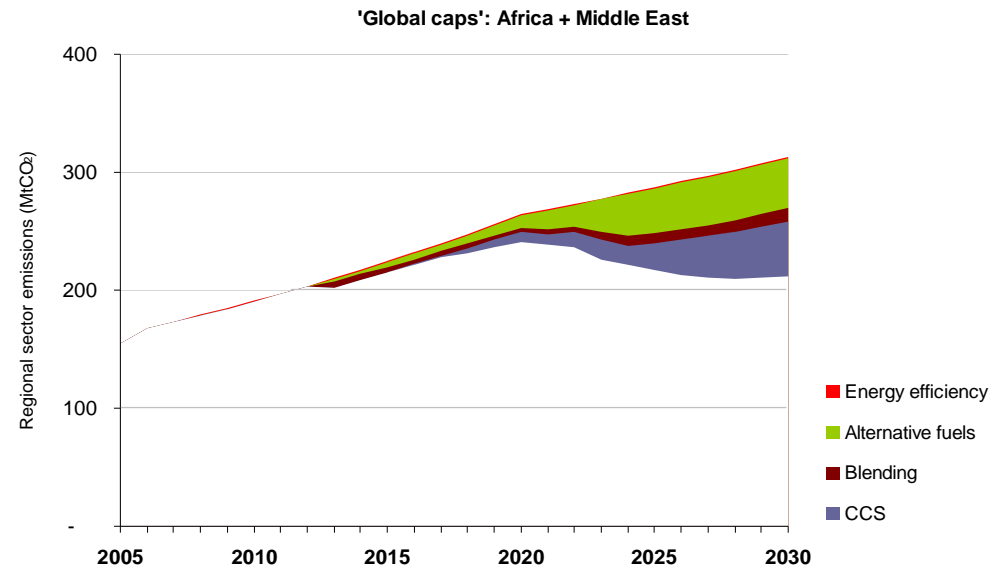
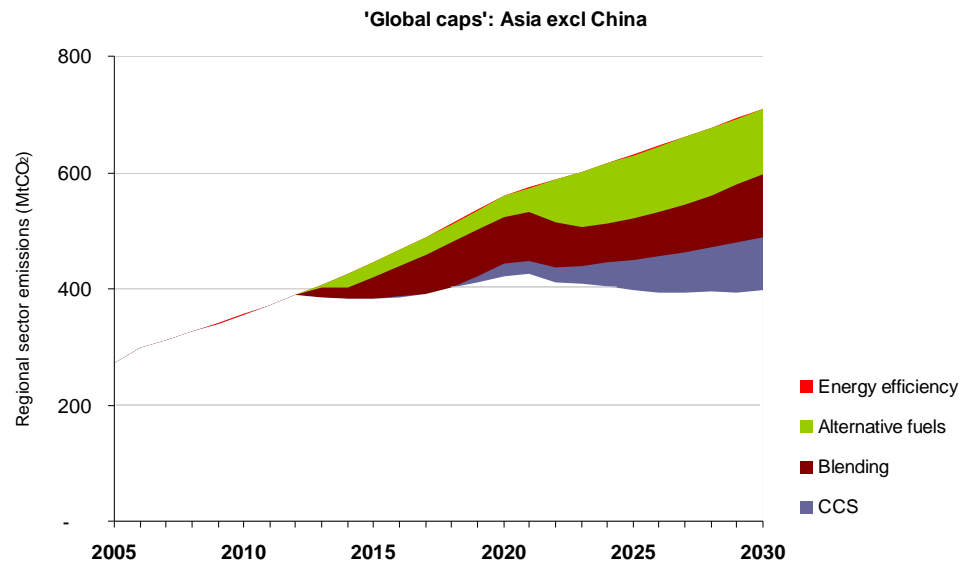
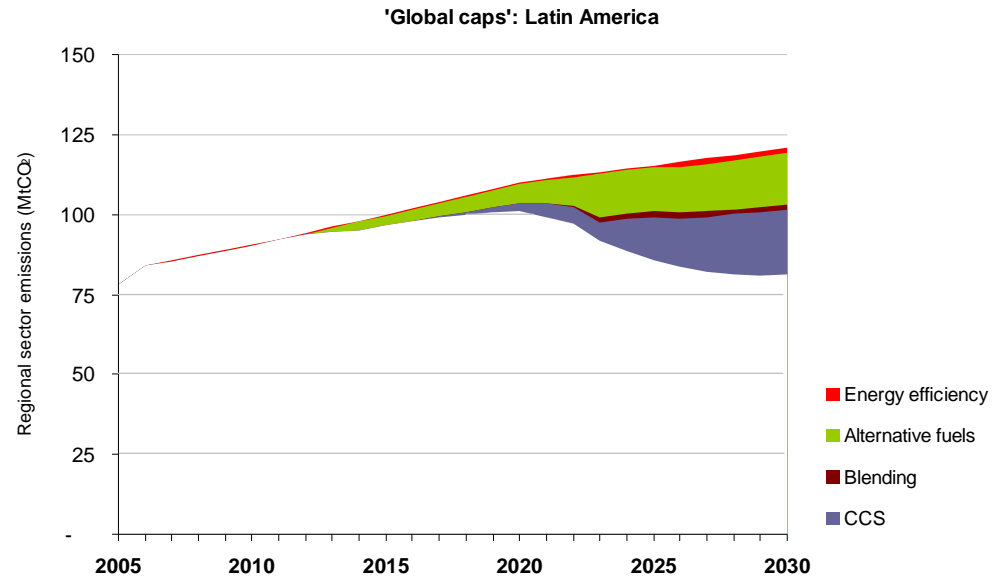
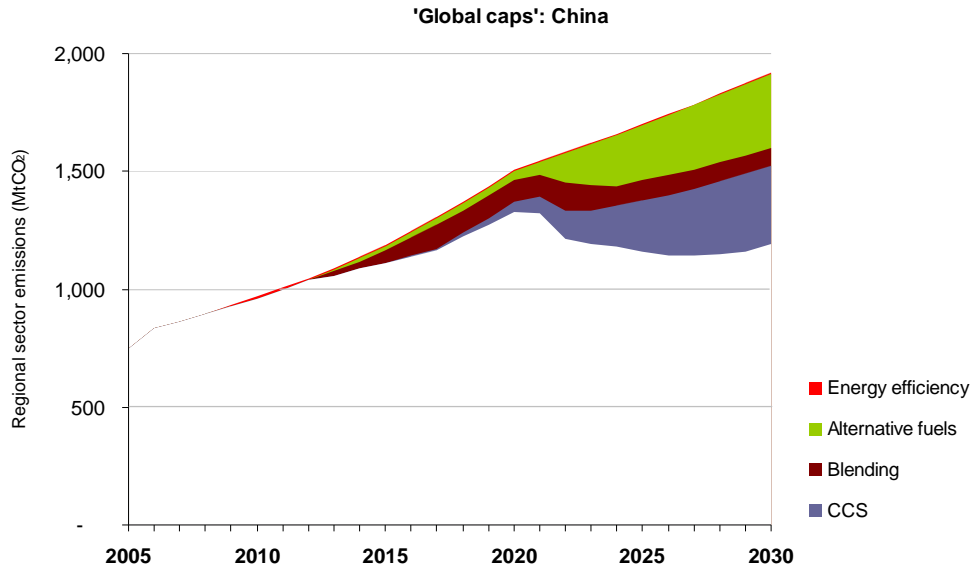


'Global caps': Japan



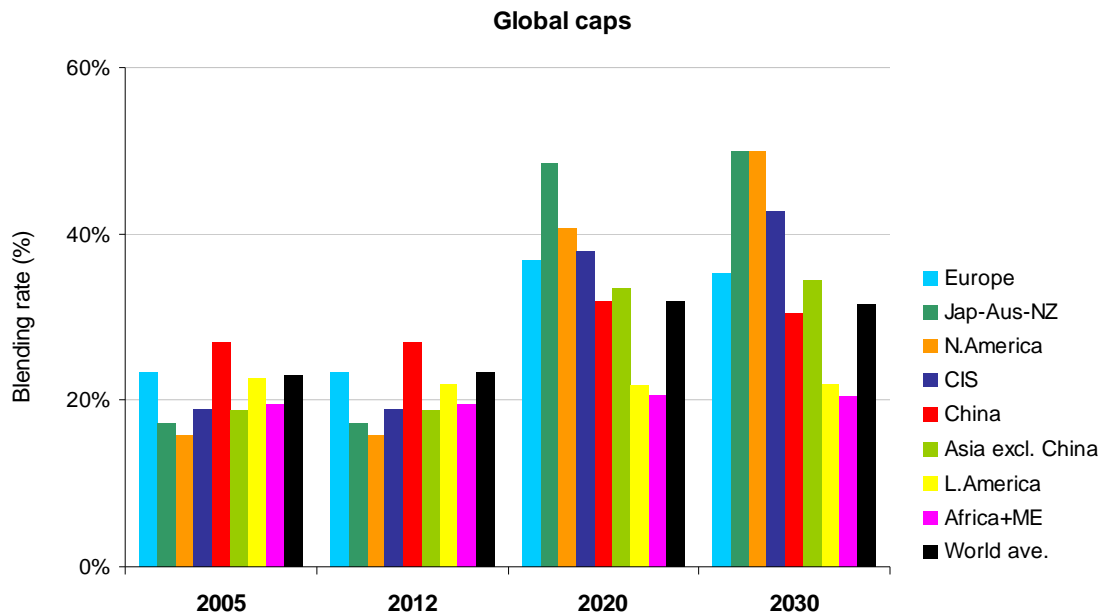
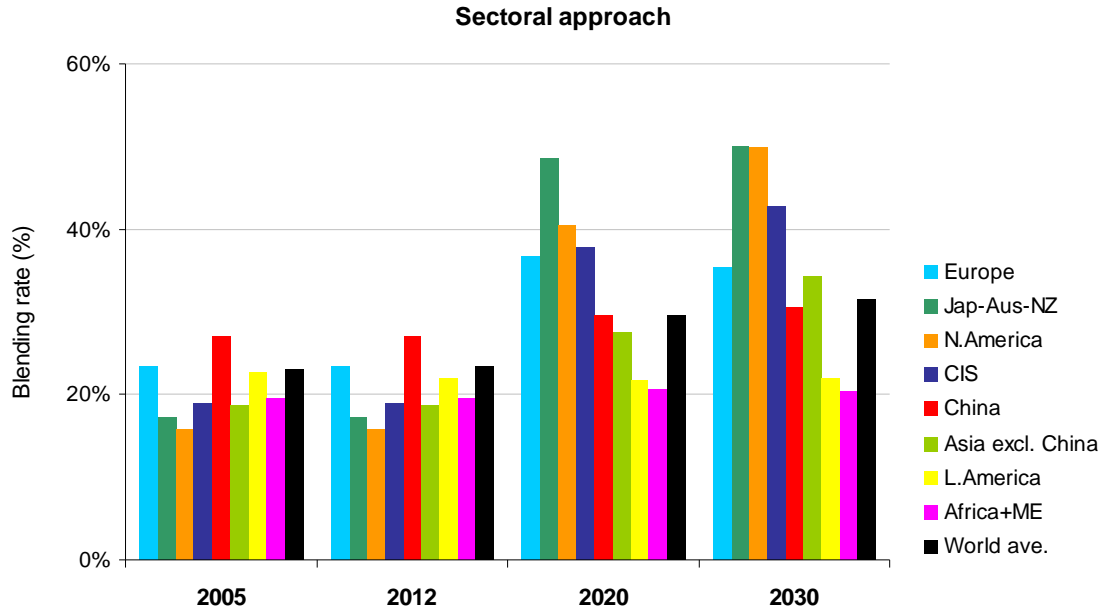
'Global caps': CIS





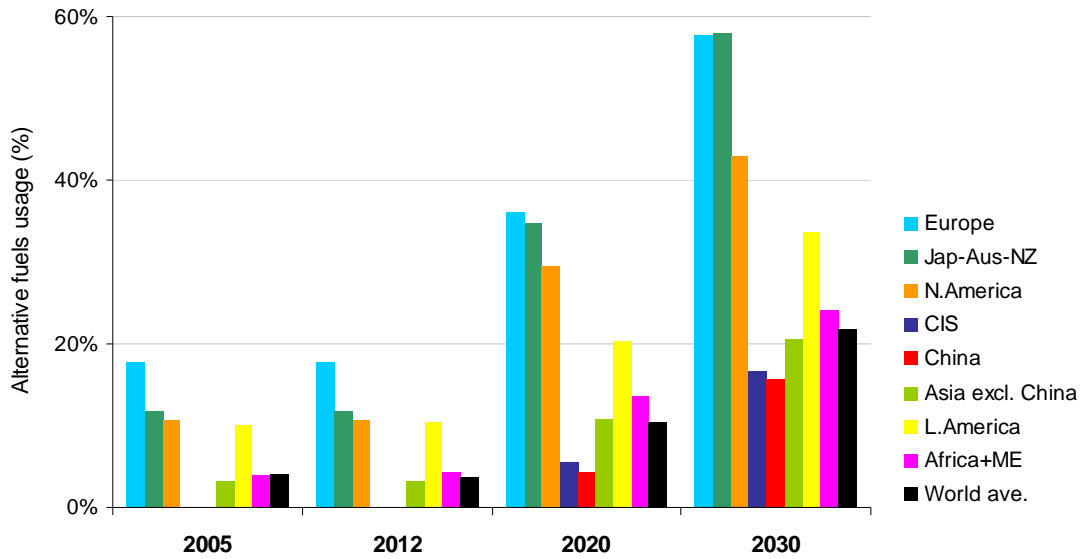
The regional potential for abatement from blending and alternative fuels can also be seen by assessing their usage levels for each region over time (rather than simply their contribution to CO₂ abatement).

The two graphs below show how blending rates vary by region under the 'Global caps' and 'Sectoral approach' scenarios. The blending rates for every region increase over time under both scenarios, most significantly for the Japan-Australia-New Zealand and North America regions, where the availability of blending materials does not serve as a barrier to greater usage. However, there are only very minor differences seen between the two sets of results (differences are most evident in the year 2020) largely due to the limited availability of blending materials in non-Annex I regions.

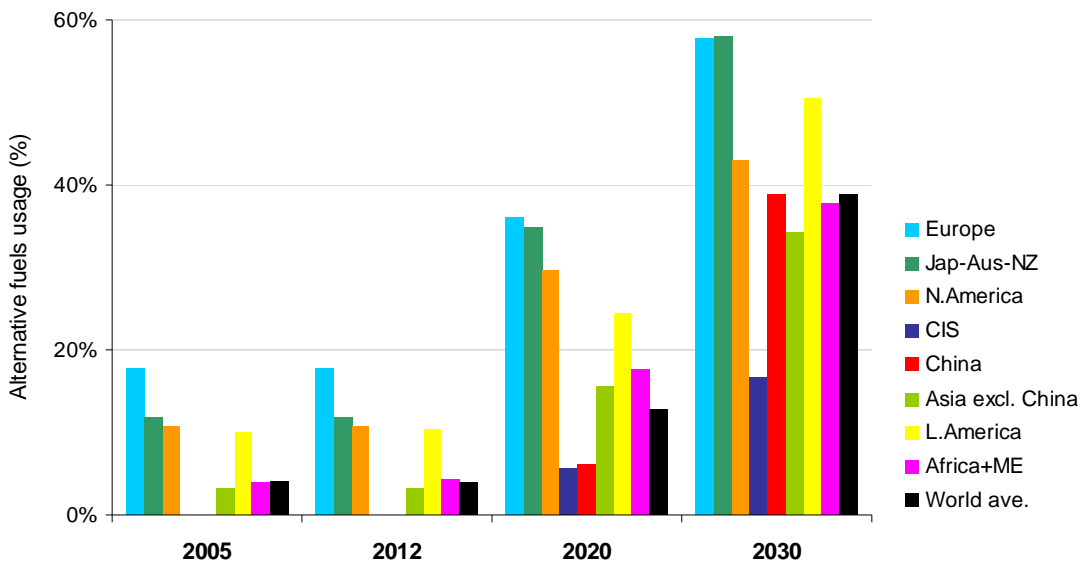


The graphs below show how the use of alternative fuels varies by region under the 'Global caps' and 'Sectoral approach' scenarios. The use of alternative fuel for every region increases over time under both scenarios, most significantly for Europe and the Japan-Australia-New Zealand region, partly reflecting the dominance of dry kiln capacity in these regions (in which alternative fuels can be combusted as a higher share of overall fuel content than for other kiln types). For non-Annex regions it can be seen that higher levels of alternative fuels usage are achieved under the 'Global caps' than under the 'Sectoral approach' scenario.

Sectoral approach

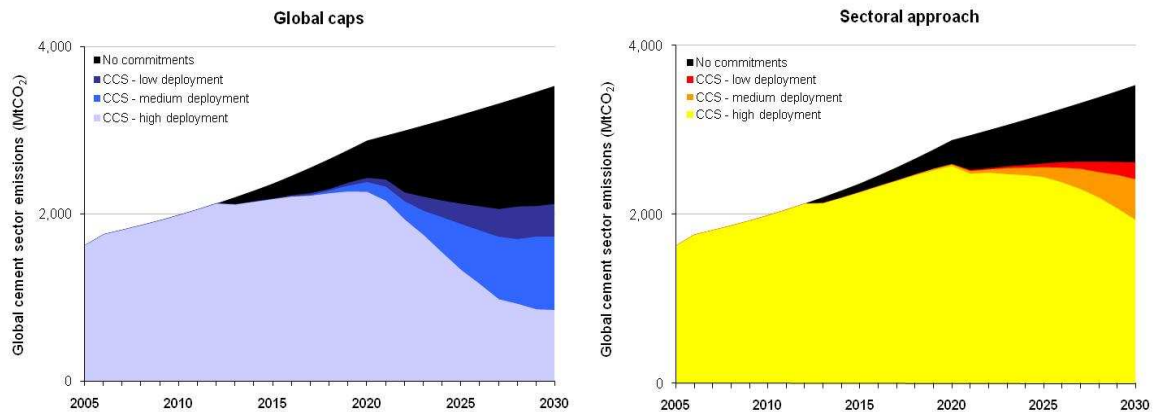


Global caps

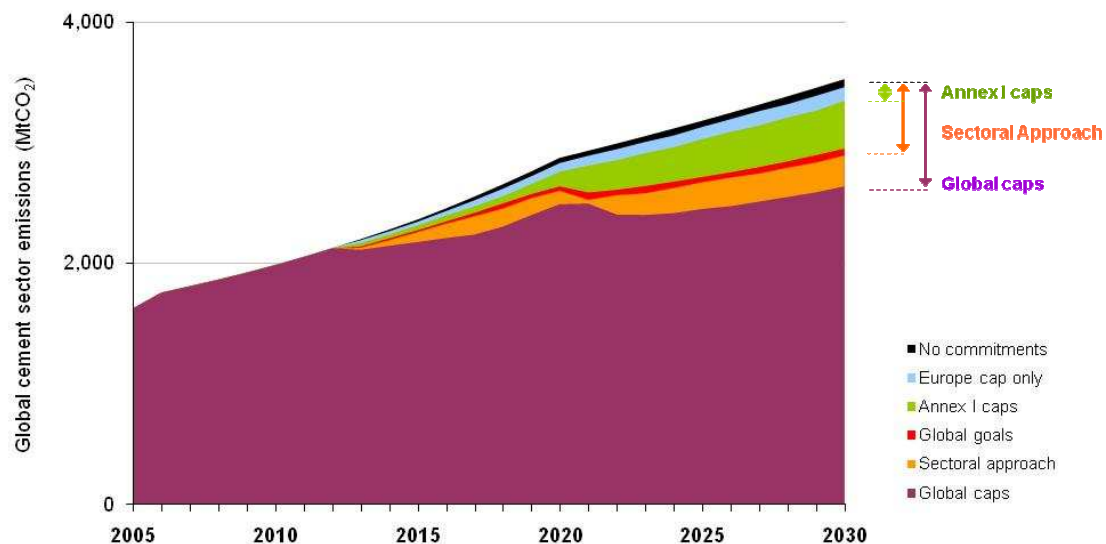


The role of carbon capture and storage (CCS)

The graphs shown below serve to illustrate the importance of CCS in achieving significant global emissions reduction in the cement sector, by illustrating absolute global sector emissions for a range of CCS *maximum* penetration levels. As shown earlier under *Policy scenario assumptions*, the base policy scenarios assume a CCS maximum penetration rate of 30%; this means that only 30% of eligible cement plants can ever deploy CCS within the modelled time period (reflecting various factors including e.g. proximity to suitable storage sites, development of CO₂ transportation infrastructure and regulatory and legal frameworks). It can clearly be seen that under both scenarios, increasing the maximum penetration levels - shown here for rates of 30%, 50% and 100% - results in significantly greater CO₂ abatement against the baseline, as CCS is progressively deployed at greater rates from around 2020 onwards.



The importance of CCS as a medium-long term abatement technology can also be illustrated by removing it as an option available to the cement sector before 2030. The graph below shows the CO₂ production forecasts under the base policy scenarios but without the availability of CCS (regardless of CO₂ price or other factors). The results can be compared with the same set of results produced earlier where all abatement options were considered available. It can now be seen that *in the absence of CCS sector abatement potential is limited*. For example, whereas with CCS available emissions reductions under 'Global caps' were forecast to be 40% less than the baseline in 2030, without CCS a reduction level of only 25% is projected. Furthermore, it can be seen that without CCS, global sector emissions are now projected to increase in absolute terms under all policy scenarios.



Trade, competitiveness and leakage impacts

Change in domestic market share

The tables below show the relative *changes* in the share of the domestic cement market by 2030 compared to the 'No commitments' baseline for groups of regions under the 'Europe cap only' and 'Annex I caps' policy scenarios. The share of domestic market is defined as the share (%) of a region's cement demand met by a region's own cement production (i.e. domestic production Mt / domestic demand Mt). The figures below show the relative change in this metric compared to the baseline. For example if a region has a 100% share of its domestic market in the baseline for a given year and loses 50% of its market share under a policy scenario in the same year, then the relative change is -50%. The corresponding loss - or increase - in domestic production is also shown in absolute Mt.

Results are shown for both (a) *free allocation* and (b) *full auctioning* of allowances. As discussed earlier, the choice of allowance allocation methodology in capped regions can have a significant impact upon results, due to the carbon cost of production influencing the regional cement price and thereby changing international trade flows. Specifically, a region will import greater volumes of cement to meet its domestic demand if the increase in its domestic cement price is high enough to encourage imports from lower cost regions able to overcome the necessary transportation costs. The cost of transportation effectively acts as a barrier to increases in imports until domestic cement prices rise beyond a certain threshold. For capped regions, the extent to which domestic cement prices increase is highly determined by the carbon cost of production, which is driven by *inter alia* the allowance allocation methodology (e.g. free allocation or auctioning). Carbon costs are calculated on the basis of only those emissions *not* covered by freely allocated allowances such that under full auctioning every tonne of CO₂ produced represents a cost which is passed on through the domestic cement price.

(a) free allocation:

Scenario	Region	2030	
Europe cap only	Europe	0%	0 Mt
	ROW	0%	
Annex I caps	Annex I	4%	25 Mt
	Non-Annex I	-0.5%	

(a) full auctioning:

Scenario	Region	2030	
Europe cap only	Europe	-41%	-133 Mt
	ROW	3%	
Europe cap only + BCAs	Europe	-4%	-14 Mt
	ROW	0.3%	
Annex I caps	Annex I	-16%	-110 Mt
	Non-Annex I	2%	
Annex I caps + BCAs	Annex I	3%	18 Mt
	Non-Annex I	-0.4%	

ROW = rest of world

It can be seen that under the base policy scenarios in which *free allocation* is assumed, little change in domestic market share is seen. However, it can be seen that where *full auctioning* is assumed the capped regions experience a significant loss of domestic market share (shown by the red ovals in the table). This now occurs as the cost of CO₂ production in these regions encourages imports from uncapped regions.

As described earlier, border carbon adjustments, or BCAs, can be applied with the intention of offsetting potential loss of competitiveness ⁽¹⁾. The *full auctioning* results therefore include policy variations in which BCAs have been applied. It can be seen that where BCAs are introduced, the observed loss of domestic market share is reduced or offset as the cost represented by the BCAs prevents imports from uncapped regions (shown by the blue ovals in the table).

These results indicate the risk of *competitiveness- or trade-driven leakage* and more specifically illustrate that (a) choice of allowance allocation methodology in capped regions may have a significant impact upon trade flows between constrained and unconstrained regions; and (b) the application of BCAs have the effect of reducing or offsetting such adverse impacts.

Carbon leakage impacts

Competitiveness- or trade-driven leakage is not the same as *carbon leakage*. If a region experiencing a loss in market share due to increasing carbon costs imports from a region in which cement can be produced less carbon intensively than in the importing region (including CO₂ from the transportation of the imported cement) then it is possible in theory for no carbon leakage to occur ⁽²⁾.

The following tables show the *carbon leakage* rates between regions whose cement sectors adopt emissions caps and those who do not, assuming (a) *free allocation*; and (b) *full auctioning* of allowances. Carbon leakage (%) has been calculated according to the most commonly defined formulation as described by the IPCC and IEA (see earlier) and represents the *increase in emissions in unconstrained regions / decrease in emissions in unconstrained regions*. In addition, any increase (or decrease) in transportation CO₂ emissions arising from greater (or less) inter-regional cement trade has been included in the calculated figures.

(1) BCAs are formulated in the model such that the importing capped region applies a tariff on the exporting non-capped region per tonne of cement imported (\$/t cement) according to the regional CO₂ price in the importing capped region in the relevant year x the carbon intensity of the imported cement (tCO₂/t cement). The BCA therefore represents an additional cost to the exporter seeking to sell cement into a capped region. Where modelled, BCAs are applied from 2013 onwards.

(2) This issue is complicated by a range of factors including the potential for deferment of abatement investment in capped regions.

(a) free allocation:

Scenario	CO ₂ leakage flow	2030
Europe cap only	Europe to ROW	1%
Annex I caps	Annex I to non-Annex I	0%

(a) full auctioning:

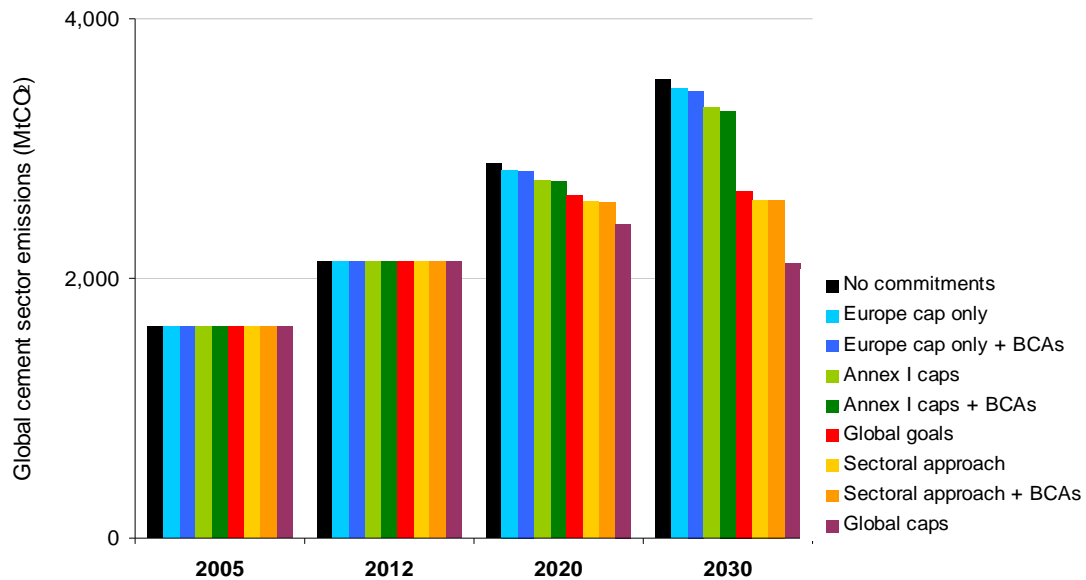
Scenario	CO ₂ leakage flow	2030
Europe cap only	Europe to ROW	56%
Europe cap only + BCAs	Europe to ROW	9%
Annex I caps	Annex I to non-Annex I	25%
Annex I caps + BCAs	Annex I to non-Annex I	0%

ROW = rest of world

The results demonstrate that significant carbon leakage occurs where allowances in capped regions are allocated by auctioning (shown by the red ovals in the second table). As demonstrated with the trade leakage results presented above, it can be seen that the leakage effect is reduced or fully offset when BCAs are applied (shown by the blue ovals in the second table).

The graph below shows the global sector CO₂ projections for each of the base policy scenarios assuming *full auctioning* of allowances in capped regions. It can be seen that with this assumption the introduction of BCAs has the effect of marginally reducing emissions compared to the same scenario without BCAs applied. This reflects the fact that BCAs enable abatement in capped regions whilst reducing more carbon-intensive imports from non-capped regions (i.e. the net global *carbon leakage* effect is shown here in terms of absolute CO₂).

This effect is marginal in relative terms because the share of cement sector emissions – and therefore abatement – from Annex I regions is relatively small. These results serve to illustrate the close relationship between the choice of allowance allocation methodology in capped regions and the potential for trade and carbon leakage within the cement sector.



CO₂ prices, reductions and targets

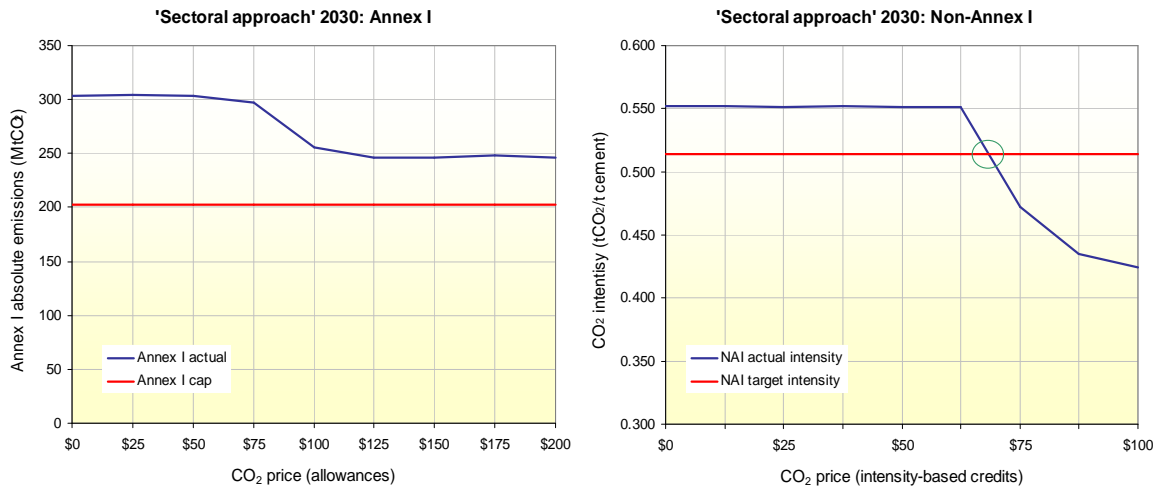
CO₂ reductions versus CO₂ prices

In order to better understand the abatement potential within the cement sector, it is important to assess how abatement efforts may respond to increases in CO₂ prices. By plotting CO₂ reduction levels against a range of CO₂ prices, the ability of the sector to meet defined targets (whether absolute caps or emissions efficiency-based goals) can be assessed as well as the ‘price point’ at which targets are met (if at all). Furthermore, differences between regions’ ability to meet defined targets can be illustrated.

The two graphs overleaf show how CO₂ emissions fall with increasing CO₂ prices under the ‘Sectoral approach’ policy scenario in the year 2030. The first graph shows the aggregated results for the Annex I regions and the second graph shows the aggregated results for non-Annex regions; note that under this scenario Annex I regions have *absolute caps* and non-Annex I regions have *efficiency-based goals*. In both graphs the cap or goal is shown by the red line and the actual performance is shown by the blue line.

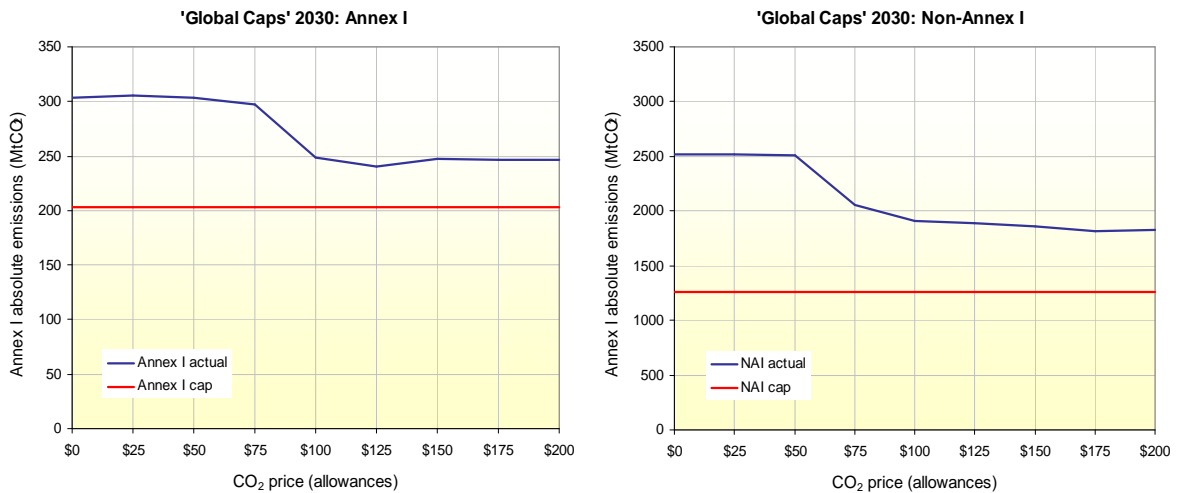
The results show that with higher CO₂ prices, the emissions reduction potential in both groups of regions increases (the key driver is the economic incentivisation of new build and then retrofit CCS). For the non-Annex I group, it can be seen that their aggregated efficiency-based goal is met when the regional carbon price is at around \$70/tCO₂ or higher (shown by the green circle). However, even for carbon prices as high as \$200/tCO₂, the Annex I group is unable to meet its collective cap level, illustrating the technical limits to abatement within the Annex I cement sector ⁽¹⁾.

(1) Greater emissions reductions are not possible for carbon prices higher than \$200/tCO₂



The following two graphs show how CO₂ emissions fall with increasing CO₂ prices under the 'Global caps' policy scenario in 2030. As before, results are shown for both Annex I and non-Annex I regions in aggregate.

Under this policy scenario, all world regions now have *absolute caps* and it can be seen that both regional groups are unable to meet their cap levels under any CO₂ price. Essentially, all abatement options available to the sector are here exhausted beyond a CO₂ price of around \$125/tCO₂. Note that under this scenario the chosen cap levels would require a 59% CO₂ reduction globally in 2030 (compared to the 'No commitments' baseline in 2030); however only 40% is possible given the underlying data and policy assumptions.



Note that the cap and efficiency goal levels (as described earlier under *Policy scenario assumptions*) are not recommended or prescribed values; neither are they based upon a bottom-up analysis of the sector's abatement potential. The values chosen are purely illustrative of potential levels that could be negotiated, against which results can be assessed.

CO₂ prices under 'Sectoral approach'

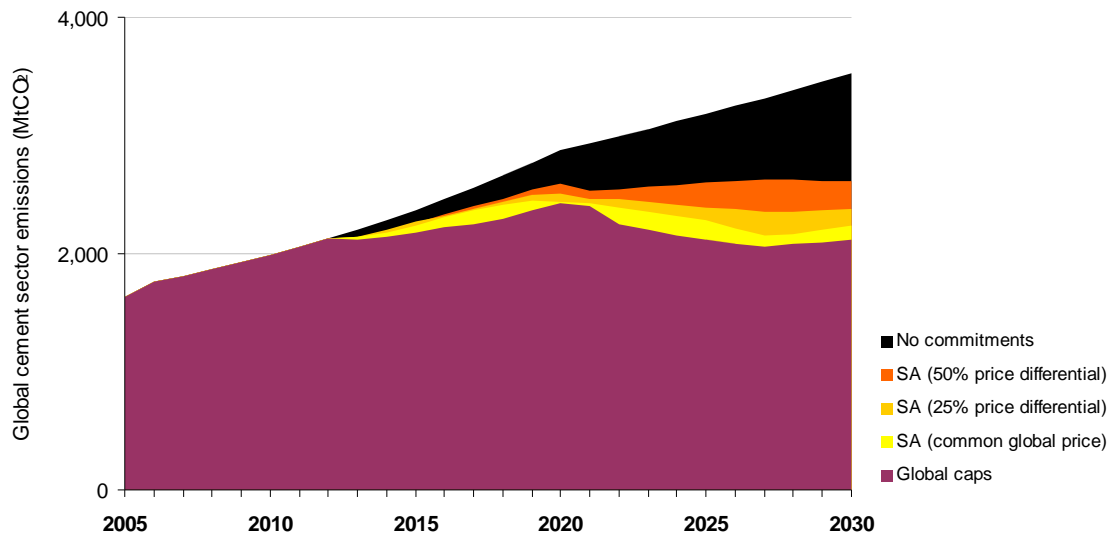
The 'Sectoral approach' policy scenario assumes that credit values in efficiency-based goal regions are less than allowance values in capped regions post-Kyoto (see *Policy scenario assumptions*). This

reflects a key assumption that these credits are discounted by the market against allowances used for compliance in capped regions. This could arise, for example, as policy-makers in Annex I regions chose to limit the flow of efficiency-based credits into their capped markets in order to ensure significant domestic mitigation efforts; in the event of significant credit supply from non-Annex regions, such limits could result in a significant value discounting.

However, a system in which there is greater - or full - fungibility of credits and allowances (as with global cap and trade) can also be envisaged, in which case there could be a much reduced difference in price between credits and allowances. An assessment of how global sector CO₂ emissions would be influenced by such a reduced price differential has therefore been undertaken under the 'Sectoral approach' scenario for three price assumptions:

- a) Credit values set at 50% of allowance market value (base assumption)
- b) Credit values set at 75% of allowance market value (i.e. a 25% price differential)
- c) Credit values equal to allowance market value (i.e. a common world CO₂ price)

The graph overleaf shows the results in terms of global sector CO₂ emissions projections; the 'No commitments' baseline and 'Global caps' emissions forecasts are also included for reference. It can clearly be seen that as prices approach a common global CO₂ price (i.e. converge upwards), the results under the 'Sectoral approach' scenario are seen to approach the results for the 'Global caps' scenario. This is because increasing the value of credits in non-Annex I regions drives greater levels of abatement from increased CCS deployment.

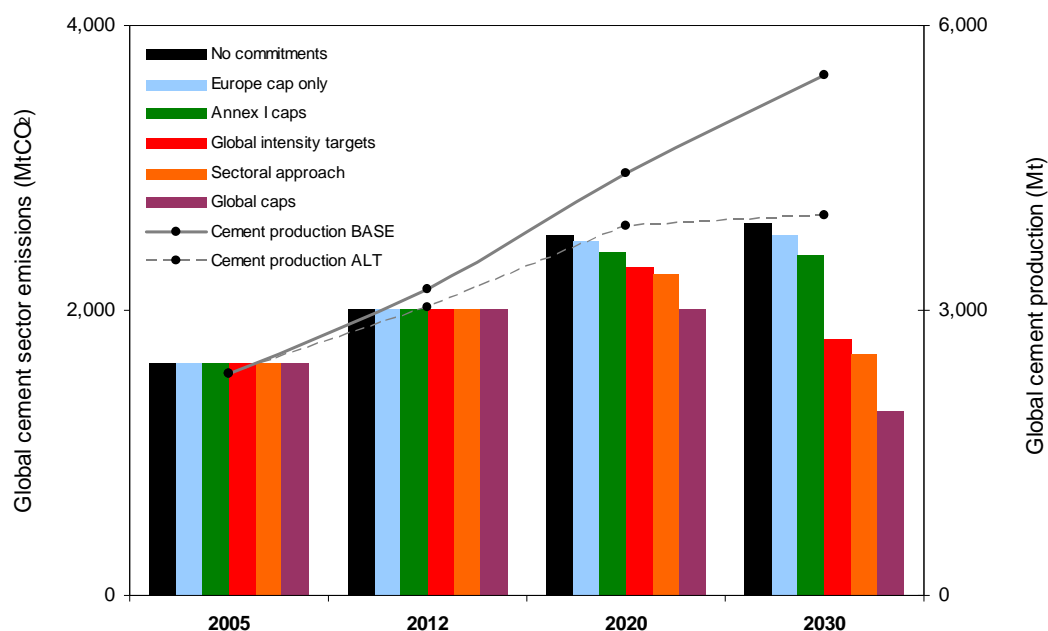


The Role of China

Cement demand in China was 1,059 Mt in 2005, representing over 45% of global demand ⁽¹⁾. Because China was a net exporter of cement in 2005, its share of global cement production was even higher. China clearly has a dominant role in the world's cement sector and is therefore critical to any efforts undertaken to reduce CO₂ emissions within the sector. Furthermore, its large share of cement production and sector emissions means that any changes in assumptions for China concerning future trends in e.g. kiln technology, production, demand and regional abatement potential in may have significant impacts upon modelled results for the cement sector as a whole.

The regional cement demand forecasts used in the base policy scenarios are based upon consolidated data from the *Global Cement Report* (2007) and regional demand growth analysis undertaken by J. P. Morgan. These data forecast more than a doubling of Chinese demand between 2005 and 2030. However, recent demand forecasts suggest more modest growth in China in which demand peaks in around 2020 and falls thereafter. For example, a study undertaken by WWF projects cement production peaking at around 1.85 billion metric tons between 2020 and 2030 and falling slightly thereafter to 1.6 billion metric tons by 2030 ⁽²⁾. Some such recent forecasts have taken a more conservative view of future Chinese economic growth and building development than in previous studies.

The following graph shows forecast global sector emissions across the base policy scenarios, in which the China cement demand forecast from WWF (show below as 'Cement production ALT') is now used.



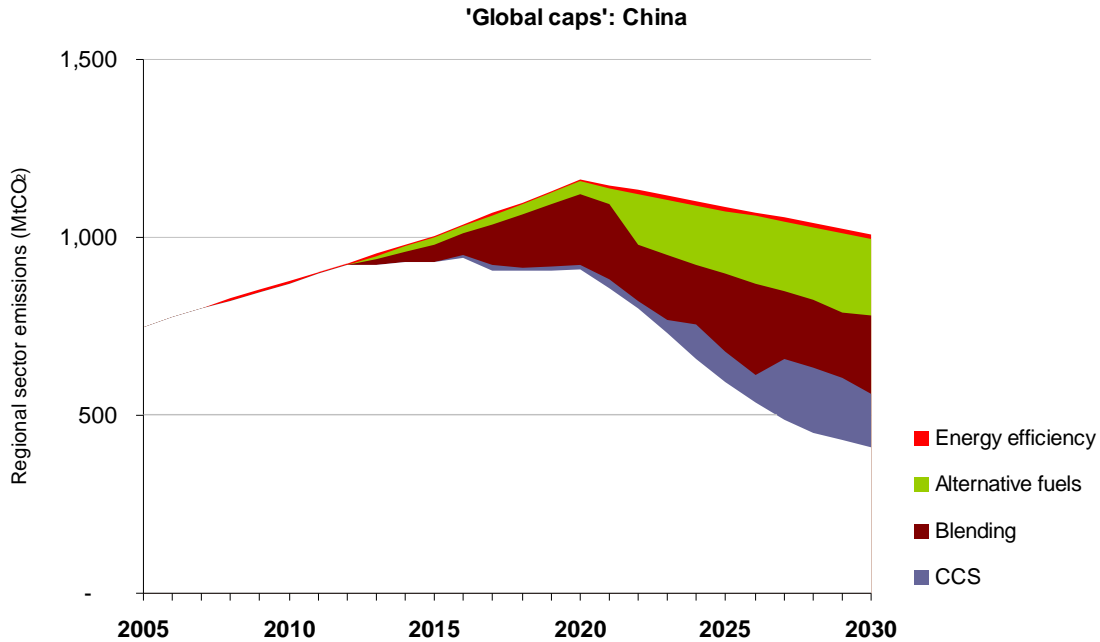
Compared to the previous forecast results, it can be seen that absolute overall emissions in future years are now lower in all policy cases, and furthermore that greater *relative* CO₂ reductions are possible under carbon policy scenarios. This latter result is due to China now producing less cement and associated emissions in future years whilst retaining the same levels of blending materials and alternative fuels. This factor can be seen more clearly by looking at the abatement potential graph for

(1) *Global Cement Report*, 2007

(2) Muller & Harnish, 2008. *A Blueprint for a Climate-Friendly Cement Industry*. Gland, Switzerland: WWF.

China under the 'Global caps' scenario, in which future cement demand is now much reduced (shown overleaf). It can be seen that when compared to the previous version of the same graph, the reduction in emissions between 2020 and 2030 in the baseline now means that the *relative abatement potential* under each of the policy scenarios is greater.

Although this sensitivity serves to illustrate the importance of the potential growth in the Chinese cement sector to overall sector abatement efforts, it must be stressed that if more conservative projections of iron and steel demand and coal-fired power generation in China were also assumed, then these would likely forecast less blending materials availability and so act as a limiting factor to abatement potential.



China is also important to potential changes in future cement trade flows arising from certain policy scenarios. Specifically, as the world's lowest cost cement producing region and the largest net exporter, its role is central to potential changes in trade flows arising from the introduction of asymmetric carbon costs.

The important role of China within trade flows is demonstrated in the two graphs shown overleaf.

As demonstrated earlier (in *Trade, competitiveness and leakage effects*) in those cases in which only some regions adopt absolute caps and *allocation is undertaken by auctioning* then the resulting increase in carbon costs and cement prices in capped region(s) may give rise to significant trade and carbon leakage effects ⁽¹⁾. The potential for trade and carbon leakage is most significant in the 'Europe cap only' policy scenario when allocation is by auctioning, reflecting the fact that in this case only Europe adopts an absolute emissions cap, whereas the rest of the world faces no carbon constraints.

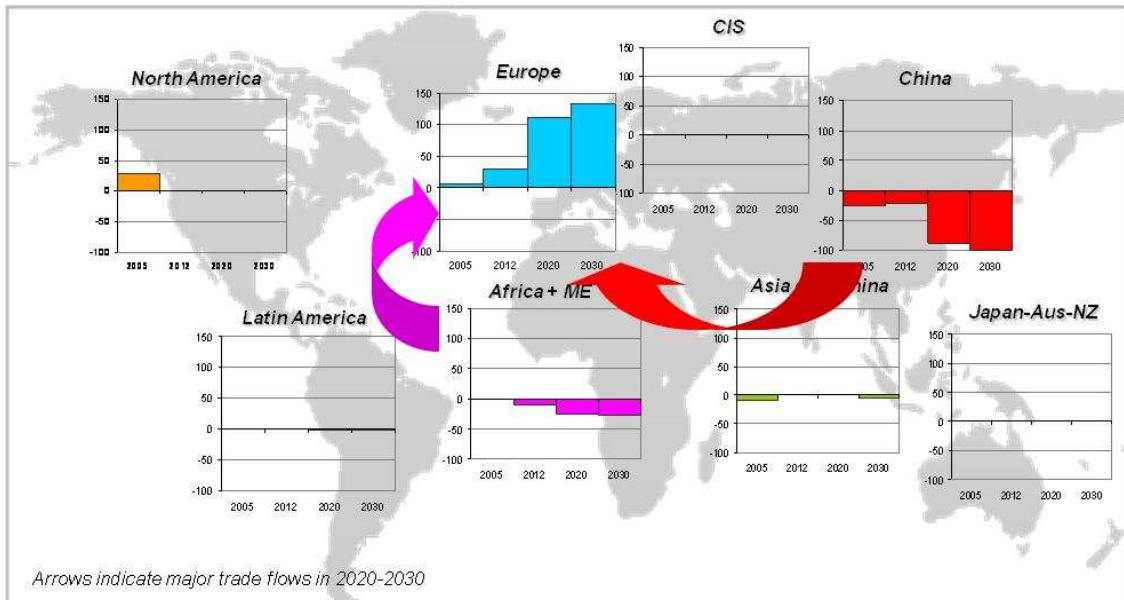
The first graph shows the associated net trade flow results (Mt cement) under this policy scenario. It can be seen that as CO₂ prices increase, Europe imports an increasingly large share of its cement

(1) Note that trade and leakage effects can also be seen where a mixture of auctioning and free allocation is adopted, although such 'hybrid' results are not presented here

demand (almost half by 2030) from unconstrained lower cost production regions - predominantly China, followed by the Africa and Middle East region.

The second graph shows the same scenario and assumptions but now with China exports limited in the model from 2012 onwards (modelled by introducing an export trade block on China). This scenario is not proposed as a potential Chinese domestic or trade policy development, but rather a simple sensitivity test in order to assess the resulting trade flows in the event of China being unable to export such large volumes of cement in future years. It can be seen that the bulk of Chinese export volumes previously seen has now been substituted with exports from other relatively low cost production regions - now predominantly the Asian and Africa and Middle East regions. The risk of trade and carbon leakage therefore remains between Europe and the rest of the world.

A. 'Europe cap only' with auctioning: *unrestricted* China exports



B. 'Europe cap only' with auctioning: China exports *limited in the model from 2012*

