
Addressing leakage concerns

Is there a case for the EU to move beyond 20% GHG emissions reduction by 2020?

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IS THERE A CASE FOR THE EU MOVING BEYOND 20% GHG EMISSIONS REDUCTION TARGET BY 2020?

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Executive summary

The findings of this paper suggest that carbon leakage needs to be readdressed if the EU's target is raised beyond 20%.

1. The impacts differ between sectors.
2. There is a trade-off between sectors benefiting from free allocation and higher emissions mitigation and prices in the electricity sector.
3. The performance of the different allocation methods differ depending on the policy objective, i.e. mitigation of carbon leakage or limitation of the European production decrease.
4. The more important the ambition of the policy, the more the instrument implemented must be designed with care.
5. More flexibility with a larger amount of international credits authorized is an option to soften impacts but in a limited way.

Introduction

The recent economic crisis and associated downward impact on production, and associated emissions levels will facilitate the EU realising its goal of reducing its GHG emissions by 20% in 2020 below 1990 levels. In other words, the additional effort required to reach this objective would be lower since the economic downturn and as such could delay the necessary investments to build a low carbon society. In particular, additional mitigation efforts undertaken by GHG-intensive industries in the EU ETS may be reduced. There is a longer-term trend of low levels of mitigation in the EU ETS even after the economy has begun to recover. This is because production levels may continue to be lower and more pertinently, there are unused European Allowances (EUAs) as well as international credits generated during the economic crisis, which could delay or reduce mitigation action. Indeed the allowances can be used for compliance during Phase III (2013-2020) of the EU ETS. One way of limiting this trend would be to strengthen the EU's target from -20% to -30%.

Although it is possible to change the cap of the EU ETS to reflect this tighter economy-wide emissions constraint (partly due to flexible mechanisms in the system such as the use of international credits), increasing the emissions constraint on some industries may lead to an increased risk of carbon leakage¹ which differs to that experienced with a 20% target. The objective of this report is to explore the impact of this shift beyond 20% on the risk of emissions leakage in GHG-intensive industries.

We undertake this analysis using the CASE II model, which allows for the examination of different targets and incorporates the possible use of international credits and different allocation modes in a unified setup.² We compare the scale of the risk of carbon leakage and the associated production losses in the EU due to unilateral carbon pricing in Phase III (2013-2020) of the EU ETS and evaluate the performances of different policy options to reduce these risks.

1. The Model

CASE II is a static and partial equilibrium model, which represents four sectors: Cement, Aluminium, Steel and Electricity³⁴. The model comprises of two regions: the European Union 27 (EU) and the Rest of the World (RoW). Sectors all have a potentially large cost impact of carbon pricing but will face different direct and indirect emissions costs as well as exposure to international competition (Hourcade et al., 2007). These sectors represent around 75% of total emissions covered by the system (Kettner et al., 2007; MEDDTL and CDC, 2010).

The model aims to evaluate the impact of different caps for the EU ETS in Phase III with respect to: production levels, price levels and trade flows in each industry. This information allows for the calculation of the leakage-to-(emissions) reduction ratio for each sector and for the whole EU ETS.

When carbon pricing policy is carried out in the EU, European firms incur three types of additional costs:

- **Abatement cost:** The abatement cost is based on Marginal Abatement Cost Curves (MACC) taken from the POLES model⁵ for the year 2020 at the aggregated EU27 level. In POLES, the MACCs are available for CO₂ energy emissions from, among others, non-mineral

¹ For a full description on the possible channels and risk of leakage faced by sectors, please see Droege et al. (2009)

² See Droege et al. (2009) and Monjon and Quirion (2011a).

³ See Annex 1 for a more complete description of the model.

⁴ Although general equilibrium effects have significant implications for climate policy, they play a larger role in estimating energy market leakage, and in carbon leakage related to competitiveness to a lesser extent (Fischer and Fox, 2009).

⁵ For a description of the POLES model, please see:

http://www.eie.gov.tr/turkce/en_tasarufu/uetm/twinning/sunular/hafta_02/5_POLES_description.pdf

materials, steel and electricity sectors. The MACCs have been used to define a curve which gives, for each CO₂ price, the decrease in unitary emissions. Abatement costs are incorporated into the model as variable costs.

POLES does not include a MACC for the aluminium sector; hence we use data from the Energy Modelling Forum EMF-21 project on multi-gas mitigation (Weyant et al., 2006).

- **Purchase of allowances:** The production cost depends on the need for purchasing or selling allowances.
- **Increase in electricity price:** The marginal production cost of cement, aluminium and steel firms increases when there is a rise in electricity prices. We assume a cost pass-through of 100% in the power sector, whatever the policy scenario modelled.

1.1. Assumptions about the Sectors

The risk of carbon leakage is highest for carbon-intensive primary commodities and semi-finished products (Hourcade et al., 2007). Consequently, the model focuses on this stage of the production chain.

For the steel sector, we model semi-finished products (e.g. slabs), because they feature higher CO₂/turnover and CO₂/value added ratios relative to finished products; hence carbon leakage is more likely to happen at this stage of the production process. We aggregate long and flat products and both production routes (basic oxygen furnace and electric arc furnace).

The modelling of the aluminium sector only covers primary aluminium, as international trade occurs mainly at this stage of production. We do not consider secondary aluminium, i.e. recycled aluminium, which involves around ten times less GHG emissions and whose production is mainly influenced by scrap availability. Aluminium has been treated in a specific way in the model because Iceland and Norway have implemented an ETS which is linked to the EU ETS since 2008 and these two countries account for almost half of the aluminium imports to the EU 27 (Reinaud, 2008).⁶ Consequently the model includes Iceland's and Norway's aluminium sector in the EU ETS.

In the model, all sectors consume electricity. We do not take into account the fact that some industrial companies produce their own electricity or the role of long-term power supply contracts (Reinaud, 2008). Moreover, we do not consider electricity savings due to the rise in power prices but we extrapolate the recent trends in the electricity consumption per ton of product.

In the cement sector, we consider that in the EU, cement may be imported as a finished product, or in the form of clinker which must be milled and blended into cement upon arrival. We assume that clinker exports from the EU to the rest of the world (RoW) are negligible, as observed in 2005. For the EU, we take into account the substitution of clinker (the CO₂-intensive intermediate product) with CO₂-free substitutes (e.g. fly ashes or blast furnace slag) as well as the substitution of domestic with imported clinker⁷.

1.2. Model Structure

All sectors are linked through the CO₂ market.⁸ The CO₂ price is determined by equalizing the demand and supply of allowances: thanks to specific emissions abatement and the decrease in

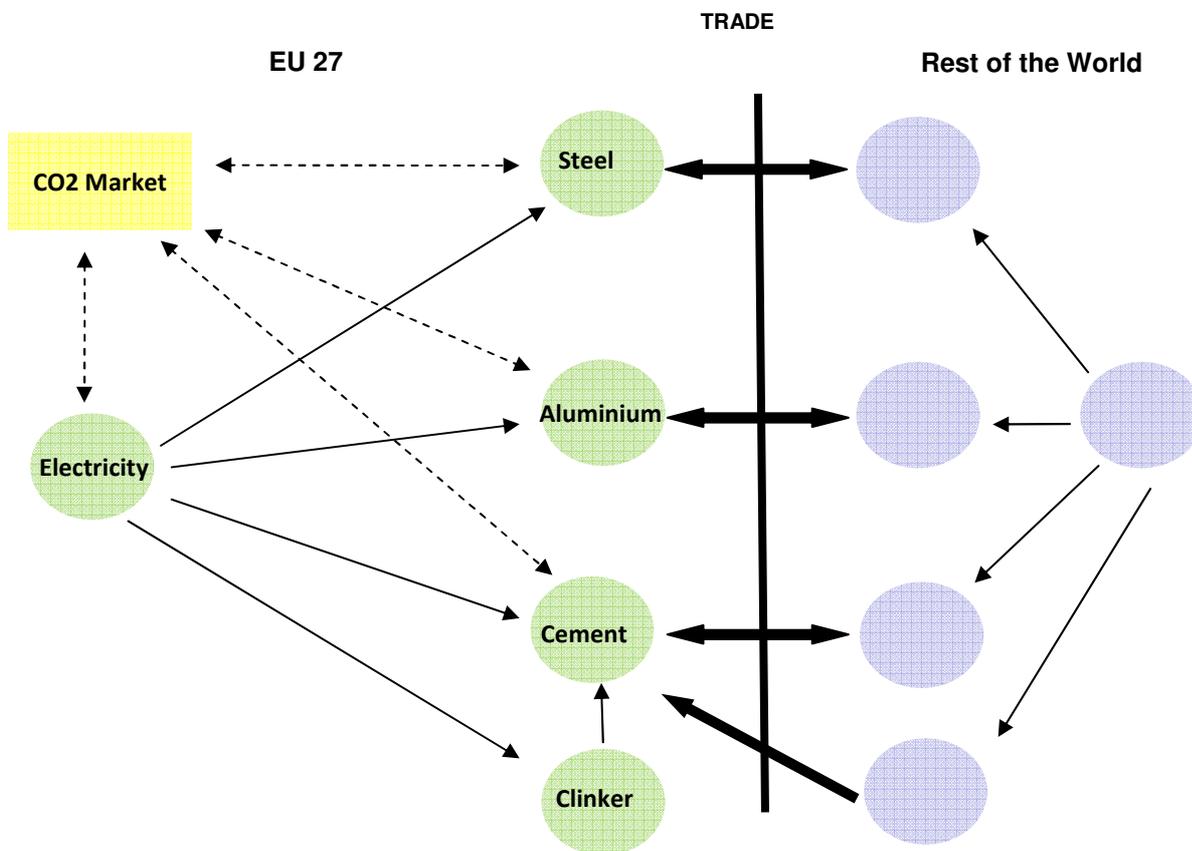
⁶ According to the UN COMTRADE database, in 2006, cement and steel exports from Iceland and Norway to the EU 27 represent around 0.4% and 1% of EU imports respectively, while cement and steel exports from EU 27 to Iceland and Norway account for around 6% and 3% of EU exports respectively.

⁷ Please see Annex I for a fuller, technical description of how cement is modelled in the CASE II model.

⁸ In fact, PFC emissions from the aluminium sector are covered as well but CO₂ market and CO₂ price are the usual terms.

production, the sum of the emissions from these sectors equals the total amount of allowances allocated for free or auctioned.

Figure 1. Model Structure



We do not model emissions in the rest of the EU ETS or emissions outside the ETS. These emissions could differ across our scenarios, due to some indirect effects (e.g. substitution between electricity with gas in building heating) but this effect is most likely to be negligible.

2. The Scenarios

Our goal is to evaluate the evolution of carbon leakage if the EU ETS cap becomes more stringent following a move from a -20 to a -30% target in 2020. The carbon leakage risk depends on a number of factors including economic growth rates, the level of international credits used in the system and the allowance allocation mode. We analyse 24 climate policy scenarios and compare them to a no-policy ("business-as-usual" (BAU) scenario⁹). The BAU scenario is simulated for 2020 without climate policy. This scenario is based on a growing GDP and changing technical coefficients (specific emissions, specific electricity consumption). Other exogenous variables stay constant (in particular production costs).

2.1. Assumptions About Economic Growth

Two scenarios are examined:

Table 1. Assumptions about economic growth

		EU 27	Rest of the world
Low-growth	2008-2015	1.1	3.3
	2016-2020	1.8	3
High-growth	2008-2015	2.2	4.2
	2016-2020	1.8	3

Source: IEA (2008, 2009)

2.2. Assumptions About the Cap and the Use of International Credits

Three scenarios are examined in coherence with the Commission staff working document accompanying the communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the regions (EU, 2010):

Table 2. Emission reductions in 2020 compared to 2005 under different assumptions provided by the EU

EU27 emissions reductions in 2020 (related to 2005)	Reference	30% with flexibility (25% domestic)	30% domestic
% GHG reduction compared to 2005	-14%	-19%	-24%
% reduction ETS compared to 2005	-19%	-26%	-34%
% reduction non-ETS compared to 2005	-9,5%	-13%	-16%
Name of Policy scenario	21flex	34flex	34dom

Source: EU (2010)

⁹ In fact, we analyze only 23 climate policy scenarios because there is no solution for one of the scenarios. See Box 1 for more details.

- 1- **Climate scenario 21flex:** objective of -21% in the EU ETS in 2020 relative to 2005 emissions, including a decrease of 19% in domestic and the remainder via the use of international credits.
- 2- **Climate scenario 34flex:** objective of -34% in the EU ETS in 2020 relative to 2005 emissions level, including a decrease of 26% in domestic emissions and the remainder achieved via the use of international credits.
- 3- **Climate scenario 34dom:** objective of -34% in the EU ETS in 2020 relative to 2005 emissions levels which is all achieved domestically, i.e. without the use of international credits.

It is assumed that the price of the EU allowances and of the international credits is the same.¹⁰

2.3 Assumptions about the Allocation Mode

We consider four allocation modes, including two different types of free allocation for the cement, aluminium and steel sectors: auctioning without border adjustment (**Auction**), auctioning with border adjustment (**BA**), (past) emissions-based allocation (**EBA**) and output-based allocation (**OBA**).

1. **Auction:** features full auctioning of allowances, without rebating the auction revenues to the firms covered by the ETS, and without any anti-leakage provision.
2. **BA:** features 100% auctioning, with border adjustment only on the imports and for direct emissions. The import adjustment is proportional to the RoW average specific emissions (direct emissions). Having said that, the implementation of such a mechanism can be problematic technically and politically (Kommerskollegium, 2010). Moreover, a border adjustment must be designed with great care to maximise its compatibility with the World Trade Organization (WTO) (Monjon and Quirion, 2011).
3. **EBA (conditional on continued operation):** features allocation is simulated similarly to the planned allowance allocation in the EU ETS for the third period, but without any representation of Dec'10 cause allowing partial ex-post adjustments. Firms in the cement, steel and aluminium sectors, considered as being exposed to leakage risk, receive free allowances, while firms in the power generation sector do not. The amount of free allocation is in proportion with their 2005 emissions and conditional on the continued operation of the firm. Indeed, new firms entering the market receive allowances, following the "new entrant reserve" provisions, while firms exiting the market do not receive allowances, following the "closure rules". Unlike the output-based allocation, the amount of allowances a firm receives is not proportional to its current output level. The reduction factor applied to 2005 emissions is the same for every sector.
4. **OBA:** features auctioning in electricity and output-based allocation in exposed industries (cement, aluminium and steel) for direct emissions. The amount auctioned is 79% (*21flex*) or 66% (*34flex* and *34dom*) of the electricity sector emissions in 2005 depending on the reduction objective retained. In every other sector, the amount of allowances allocated per unit produced is calculated by applying a reduction ratio to the 2005 specific emissions. Again, the reduction ratio is equal across sectors and calculated so that the emission cap is 79% or 66% of 2005 emissions.

¹⁰ There has been a convergence between the prices of the EU allowances and the international credits on the spot markets. From April 2009 to April 2010, the difference between prices has been comprised between 1 and 3 € (price of the EU allowances is between 12,87 and 14,61 € and price of the international credits is between 11,02 and 13,17€) (CDC, 2010).

2.4 Common Features across Climate Policy Scenarios

The simulations will be made assuming “all other things equal”. In other words, it is assumed that there will be a CO₂-price for the CO₂-intensive industries only in the EU27. It is difficult to know if this will still be true in 2020. Deliberations continue regarding the introduction of a carbon price in a number of regions, including the USA, Australia, Japan and South Korea but there is no certainty about what will be introduced by 2020. In addition, the pledges outlined in the Copenhagen and Cancun Accords could lead to a mix of measures which do not really affect the production cost of these industries. But the reader should keep in mind that by assuming unilateral carbon pricing in the EU, we may overestimate the impact of the EU ETS on industrial competitiveness, hence carbon leakage. However, our focus is on comparing the relative impact of policy options rather than on estimating absolute values, and there is no reason to think that these uncertainties regarding international climate policies will change the ranking of policy scenarios in terms of their impact.

3. Results

Results are reported for the year 2020, i.e. the last year of the third phase of the EU ETS.

3.1. The CO₂-constraint in the EU ETS

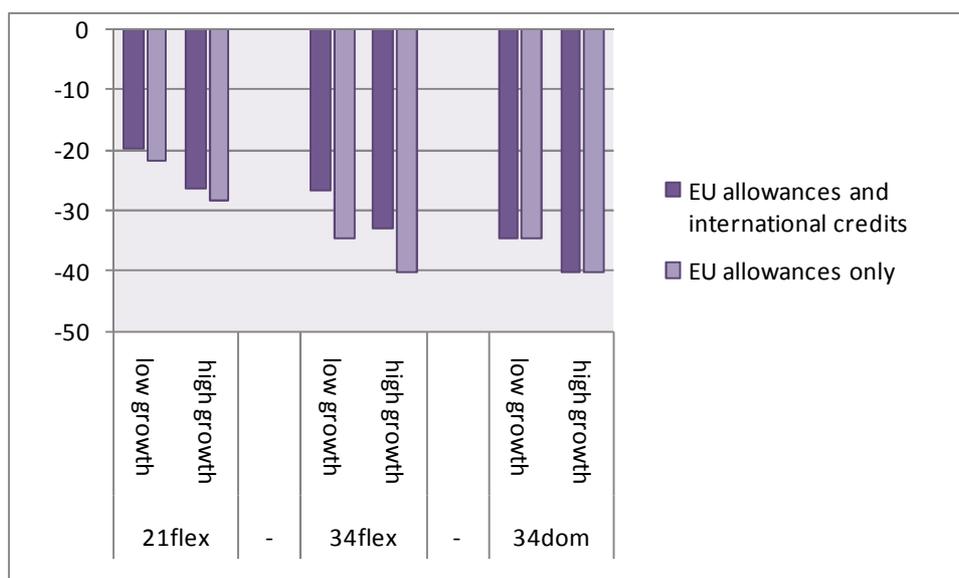
The use of international credits in the system softens the emissions constraint on sectors. Indeed, firms have an additional option of increasing their emissions to a certain extent if they use offsets. This does not mean that the firms can increase their emissions freely but the increased amount of permits in the system leads to a decrease in the CO₂ price. Table 3 (last line) displays the progressive reinforcement of the constraint.

Table 3. Amount of available permits in the EU ETS in 2020 (MteCO₂)

	Scenario 21flex	Scenario 34flex	Scenario 34dom
European allowances allocated in 2020	1279.8	1069.2	1069.2
International credits used in 2020	32.4	129.6	0
Total	1312.2	1198.8	1069.2
Decrease of domestic emissions (/2005)	-19%	-26%	-34%

Figure 2 reveals the important role of economic growth on the modelling results: between low and high growth scenarios, the additional emissions reductions rise significantly. Without international credits, the most stringent objective imposes an emissions reduction of around 40%, relative to the BAU scenario if the growth is high. The international credits partly alleviate the constraint by increasing the number of permits available, which decreases their price.

Figure 2. Emissions decrease between the BAU scenario and the climate scenarios and international credits contribution to the objective (%)

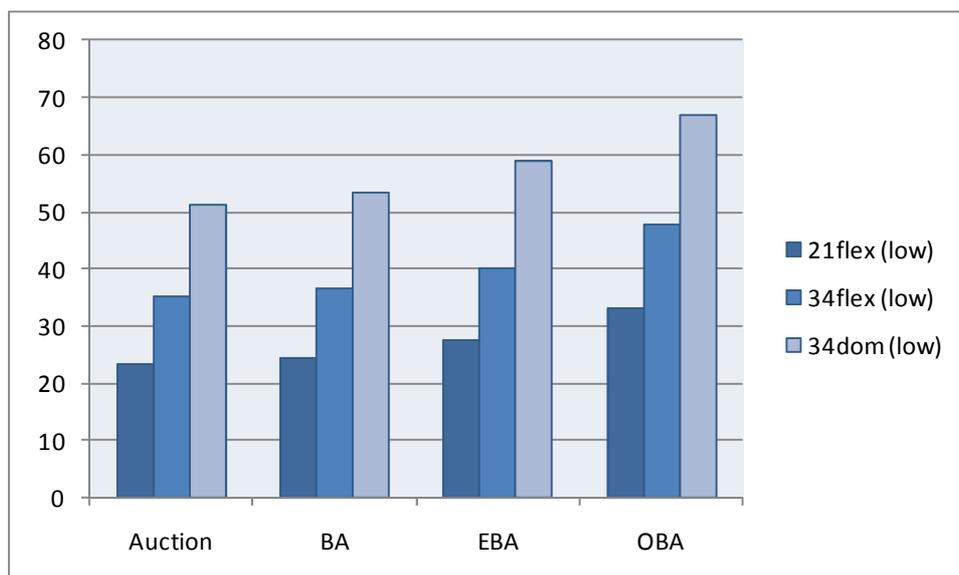


3.2. CO₂ price, Public Revenues and Carbon Leakage

The CO₂ price varies a great deal depending on the assumptions made in each scenario. Firstly, increasing the stringency of the overall cap will raise the price of permits: the price is at least doubled between the *21flex* scenario and the *34dom* scenario, regardless of the allocation mode modelled.

Secondly, the allocation mode plays a crucial role in determining the price level. In Figure 2, the allocation modes are placed in order of CO₂ prices. The ordering is always the same regardless of the assumed levels of economic growth. The CO₂ price is lowest under *Auction* and highest under *OBA*. The CO₂ price is slightly higher under the *BA* scenario than under *Auction*, because border adjustments limit the substitution of foreign production for domestic production, which is one way of reducing CO₂ emissions attributed to EU producers. Hence a higher CO₂ price is needed to get lower unitary emissions. The price is higher under *EBA* and *OBA* than under *BA* because free allocation constitutes a subsidy to the production of polluting goods, which increases the demand for allowances, hence the CO₂ price. The difference between the two free allocation modes is the following: *OBA* gives a “subsidy” for each ton of product produced, while *EBA* gives the same “subsidy” when a firm exists, regardless of its production level. This generates different incentives as explained in Box 1. In both cases, this leads to higher production levels than *Auction* and *BA* scenarios. Consequently, to generate the same aggregate emissions levels under *EBA* and *OBA* as in the other scenarios, lower CO₂ emissions per unit produced are required, which implies a higher CO₂ price.

Figure 3. Carbon price of the allowance (Euros/tCO₂) in low-growth scenarios

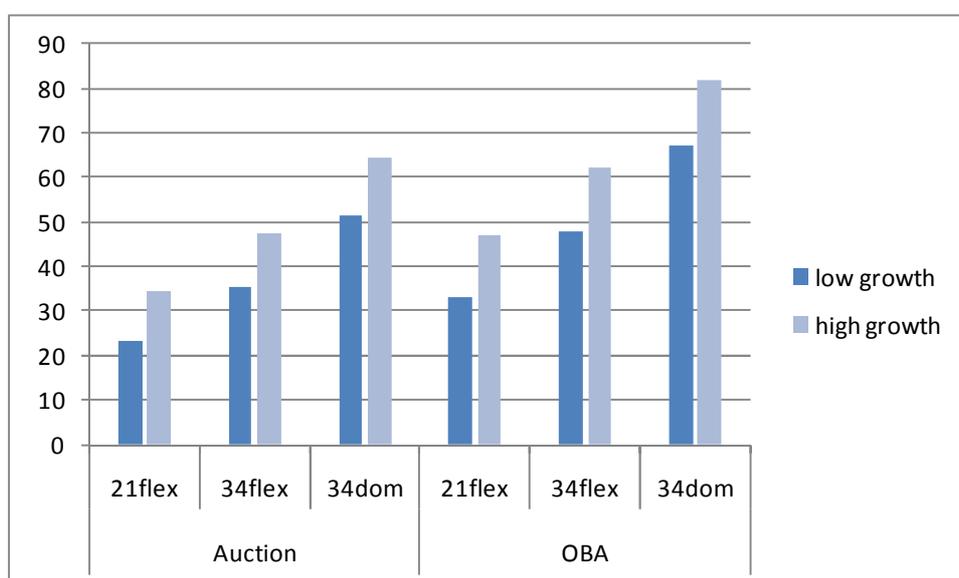


Lastly, the economic growth level has a big impact on the CO₂ price as well. Figure 3 presents the CO₂ price depending on the assumption about the level of economic growth. For the sake of clarity, results are displayed only for *Auction* and *OBA*, the scenarios in which the price is the lowest and the highest. The ordering is always the same: *Auction*, *BA*, *EBA* and *OBA* regardless of the assumptions on the level of economic growth. Between the low and high-growth scenarios, the difference in CO₂ price is at least 11€ and increases as the emissions constraint becomes more stringency. The difference in carbon prices due to the economic growth rates is biggest under *OBA*, more than +14€. Notably, the price reaches above 80€/tCO₂ under *34dom*. We note that the price

in the scenario *21flex* with high-growth is very close to the price in the scenario *34flex* with low-growth.

What to think about the high level of the CO₂ price? Free allocation helps to preserve the production level; i.e. reducing emissions through reducing production, is limited. The emissions decrease is mainly attributable the reduction of the specific emissions. However, increasing abatement of specific emissions may become more increasingly difficult and costly. If in reality, the abatement potential is less than those assumed in the model we can expect to see an increase in imports and associated risk of carbon leakage. For example, the results for our assessment of the impact of *OBA* scenarios rely on the assumptions that European installations will maintain their production levels, while limiting the increase in price. Due to these reasons and broader difficulties with accurately modelling uncertainty in Phase III of the EU ETS, the higher estimates of carbon prices in our scenarios we would suggest viewing the absolute prices with caution and instead focus on the relative impact on carbon prices from changing different assumptions in the scenarios.

Figure 4. Carbon price of the allowance in low and high growth scenarios under Auction and OBA (Euros/tCO₂)



Box 1 – Differences between the Free Allocation Modes

The two allocation modes result in lower losses to production relative to the *Auction* allocation, but the incentives that are created for firms differ. This comes from the different natures of the free allocation modes. *OBA* gives a “subsidy” for each ton of product produced, while *EBA* gives the same “subsidy” when a firm exists, regardless of its production level. Consequently *OBA* provides the incentive for each firm to produce (and to sell) more output since they then receive a proportion of free allocation for each ton produced. Nevertheless the proportion of allowances received decreases with the total quantity produced. On the contrary, *EBA* incentivises new firms to enter the market since each firm receives a quantity of free allocation, conditional to a certain activity threshold. But the quantity of free allowances isn’t linked to the production levels of the firm. Thus, under *EBA*, the number of the firms is assumed to increase relative to *BAU*, while under *OBA* their number is relatively stable. If we compare *OBA* and *EBA*, there are more firms under *EBA* however each firm is assumed to produce a lower quantity.

Under *EBA* there are more firms which leads to more competition in the market, this is assumed to reduce the price in the EU markets. In foreign markets, the impact of an increased number of EU firms will have a smaller impact on competition since the EU firms represent only a proportion of the overall markets. The pricing behaviour of the firms in EU markets and in foreign markets is different. Under *OBA*, the number of firms is stable but each firm has the incentive to produce more for EU and foreign markets and, EU exports are reduced less under *EBA* than under *OBA*.

On the other hand, limiting the price increase in EU markets mitigates the increase of the importations under *EBA* and *OBA*.

The last important difference, which explains a large part of the different performances limiting carbon leakage, comes from the use of imported clinker in the cement sector. Under *EBA*, the firms receive the same amount of EU allowances regardless of the quantity of clinker produced, while under *OBA* free allowances are given in relation to the quantity of clinker produced (the most CO₂intensive part of the production process). Firms have the incentive to limit clinker imports under *OBA*, while the quantity of imported clinker is boosted under *EBA*.

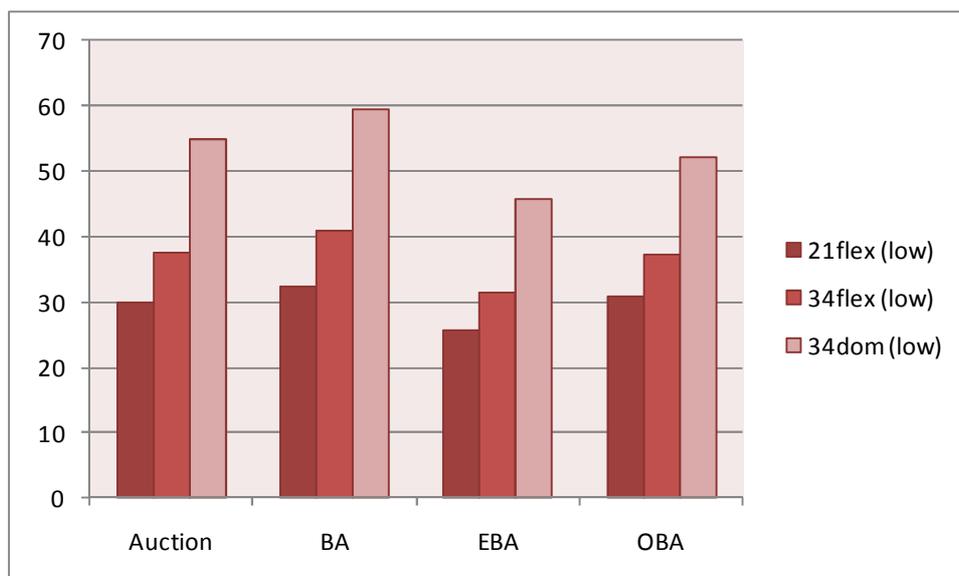
Finally, note that there is no equilibrium solution in the scenario *EBA/34dom* because the CO₂ price is increased so much (superior to 60€/tCO₂eq.) that the model no longer converges for this scenario. The incentives to enter the cement market due to the free *EBA* are so high than the number of cement firms is no longer determined by the free-entry condition since the fixed costs are paid by the free allocation. It is to note that the *EBA* scenarios do not model the clause of Dec'10 allowing partial ex-post adjustments, which would limit this effect. Consequently, the rules chosen for the third period are maybe between an *EBA* and an *OBA*. Moreover, in the real life, other factors will limit the number of new entrants in the cement sector. Then, this may lead to windfall profits in the cement sector.

Whichever the growth level and whichever the allocation mode, the public receipts from auctioning are superior in the *34dom* scenarios relative to the *34flex* scenarios, even though the same amount of EU allowances is auctioned. This is because the CO₂ price is higher in the *34dom* scenario.

As is apparent in Figure 4¹¹, in the low-growth scenarios, the *BA* scenario generates more revenues than the *Auction* scenario, while the *EBA* scenario generates the least amount of public sector revenues. Nevertheless, the collected money amount is still significant even though a large percentage of allowances is allocated for free. This is because the remaining allowances are sold at a higher price. *OBA* generates more public revenues than *Auction* under *21flex*, but less under *34flex* and *34dom*. The scale of revenues generated depends on CO₂ price levels (always superior under *OBA*) and the quantity of allowances auctioned (always inferior in *OBA*).

¹¹ These figures are similar to those of Cooper and Grubb (2011) but just for one year.

Figure 5. Revenues from auctioning and border adjustment in low growth scenarios (billion €)



As is apparent in Figure 6, revenues from the border taxes on imports are small relative to revenues that could be generated from auctioning EUA allowances (our estimates indicate they are around 3-4% of the total revenues generated). Between the low and high-growth scenarios, the public revenues increase proportionally to the CO₂ price.

Figure 6. Revenues from auctioning and border adjustment in BA scenarios (billion €)

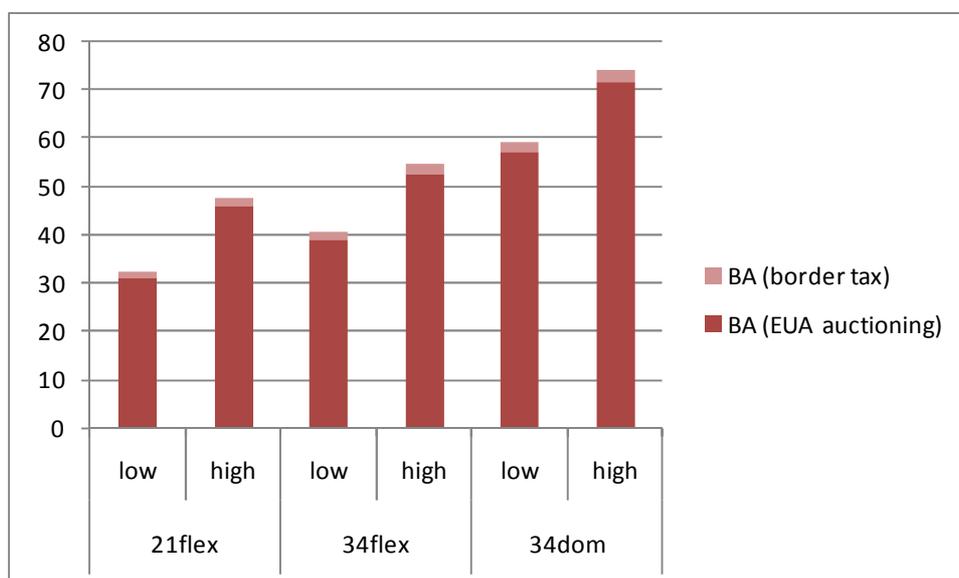
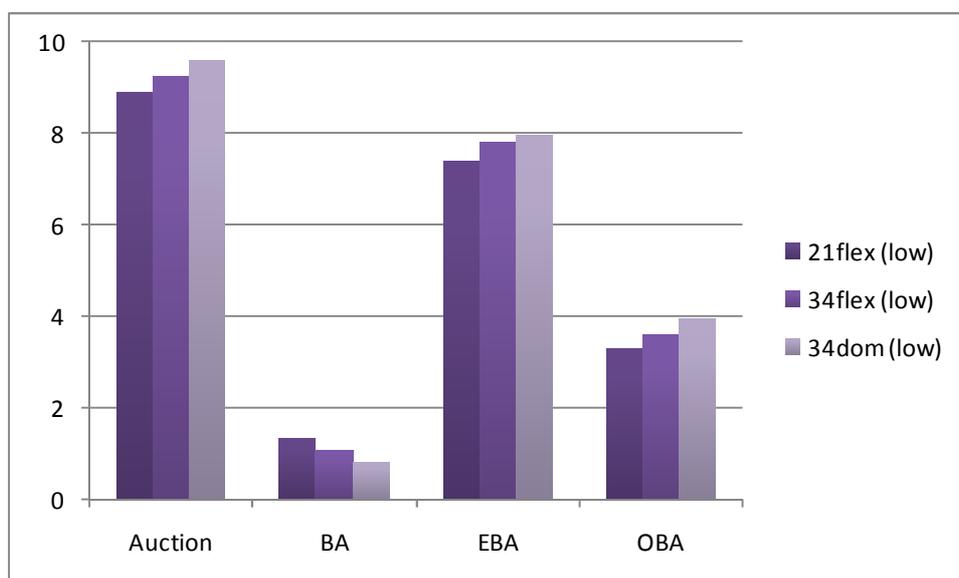


Figure 7 displays the leakage-to-reduction ratio, i.e. the increase in the RoW emissions divided by the decrease in EU emissions, in low-growth scenarios. The ratios are almost identical in the high-growth scenarios but the increase of the emissions in the RoW is substantially higher when economic growth rates are high, as apparent in Figure 7. This is largely due to the higher CO₂ price.

The leakage-to-reduction ratio is the highest under *Auction* and the lowest under *BA*. Except for *BA*, the ratio increases with the stringency of the constraint. Under *BA*, the increased CO₂ price makes the consumption of CO₂-intensive goods more and more expensive regardless of their origin.

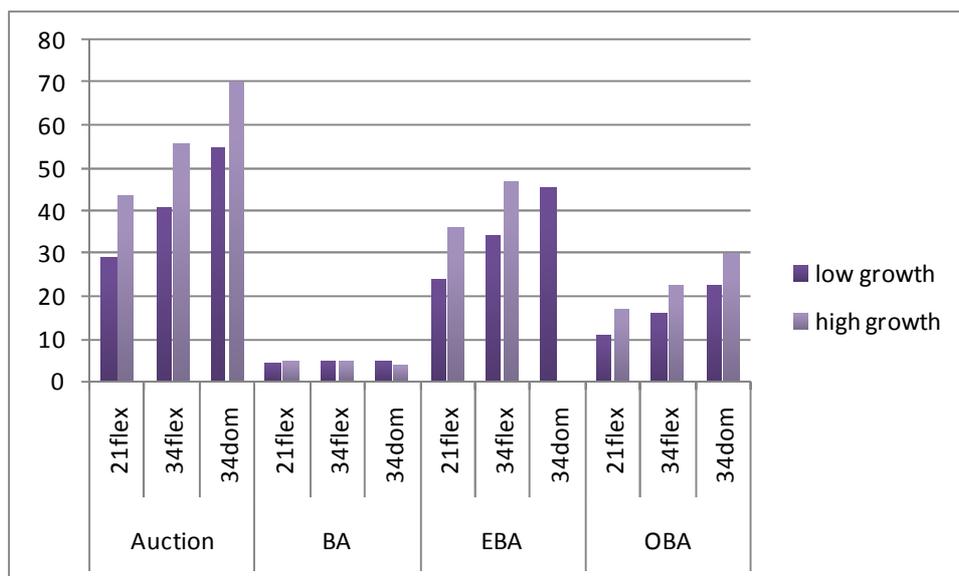
European consumption is then reduced, and limits import levels and emissions associated with production in the RoW.

Figure 7. Leakage-to-reduction ratio in low-growth scenarios (%)



The two free allocation modes perform very differently with respect to their ability to limit leakage: while the performance of *OBA* to limit carbon leakage are relatively good (between 3 and 4%), the ratio under *EBA* is only slightly lower than under *Auction*. This is because the two free allocation modes provide different incentives to firms as explained in Box 1. Under *EBA*, carbon leakage comes from a decline in the levels of European exports and more significantly, from an increase in clinker imports (which accounts for more than 30% of the leakage levels estimated).

Figure 8. Emission variations in the rest of the world related to BAU (MteCO₂)



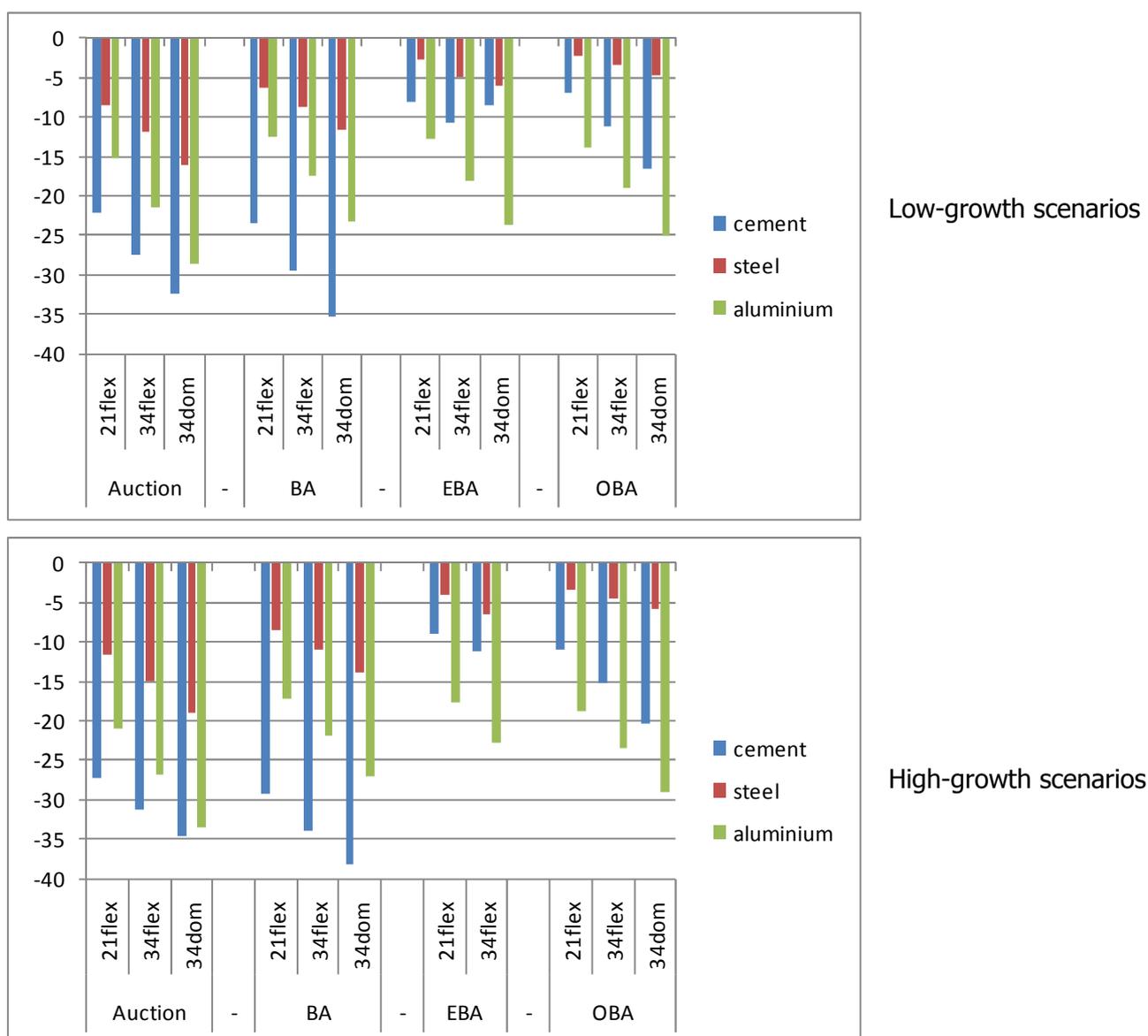
Finally, Figure 9 displays the variations in production levels in the EU relative to the BAU scenario. The results are very different depending on the allocation mode. While the free allocation modes perform relatively well in limiting the decline in European production levels, *Auction* and *BA* induce

large losses. Consequently, the most appropriate remedial policy measure to address leakage will differ depending on policy objectives.

Moreover the differences can be important among the sectors. The cement and aluminium sectors are the most impacted under *Auction* and *BA*. Nevertheless, under *BA*, the decrease of European production doesn't equate to high levels of carbon leakage. Indeed, *BA* limits the substitution of European products with foreign products and the losses in EU production are mainly attributable to the decrease in consumption of CO₂-intensive products EU.

The free allocation modes both limit the decrease in production in the cement and the steel sectors, while the aluminium sector, impacted by the electricity price above all and the associated costs of indirect emissions, continues to witness large reductions in production levels. Interestingly, across all of our scenarios, the cement sector is more impacted than the steel sector.

Figure 9. Production variation in the cement (C), steel (S) and aluminium (A) sectors (% variation/BAU) in the low-growth scenarios



3.3. Sector-by-Sector Analysis

For the sake of clarity, we present only the results for the low-growth scenarios. When growth is high, the constraint is reinforced which leads to a higher CO₂ price. However, qualitatively the impacts are similar to those in the low-growth scenarios and by selecting a single assumption on growth rates, we are able to better see the relative impact of the different allocation scenarios.

3.3.1. Electricity sector

The most important difference between the electricity sector and the other sectors is the fact that it is not exposed to leakage risk and does not receive free allowances in any of the scenarios. This leads to results for the electricity sector which differ from other sectors.

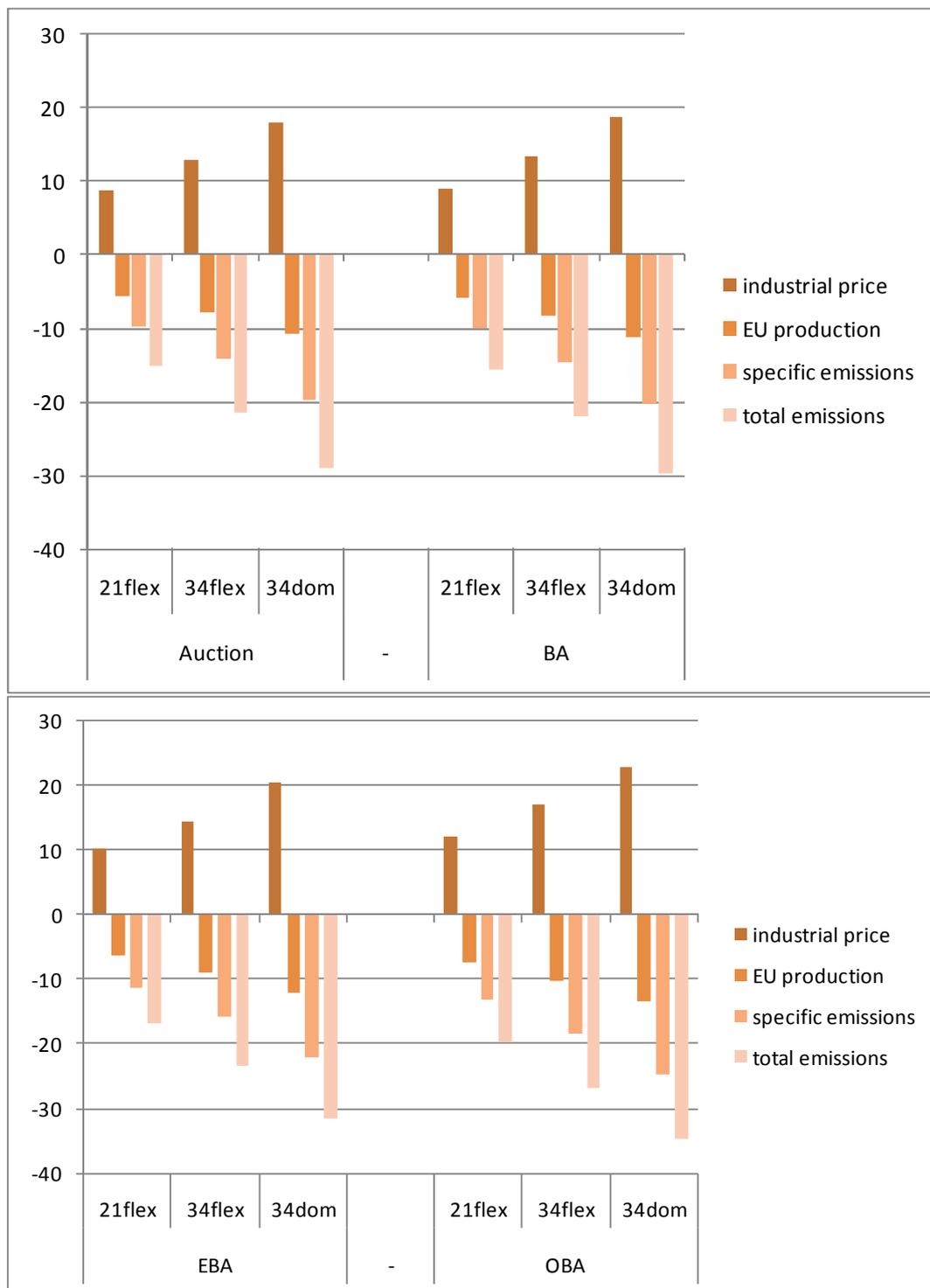
Under *Auction*, as shown in Figure 9, the electricity price for industrial consumers in the EU increases 8% to 18% depending on the stringency of the CO₂-constraint. The price increase is a little higher under *BA* and significantly higher under *EBA* and, in particular, under *OBA*. This last result is explained by the higher CO₂ price, but also by the fact that the electricity producers must buy all the allowances they need, while other sectors benefit from free allowances, leading to more emission reductions in the electricity sector.

The decrease in specific emissions depends on the allowance price. They fall the most under the *OBA* scenarios and are relatively similar in the *Auction* and *BA* scenarios. The ranking of the allocation scenarios is the same when we focus on the total level of emissions reduction in the electricity sector.

Electricity production decreases the most under *EBA* and *OBA* scenarios. When the CO₂-constraint is strengthened, production levels decrease by around -2.5% from *21flex* to *34flex* and around -3% from *34flex* to *34dom*. The scale of these production decreases is very similar regardless of the assumptions on allocation mode and levels of economic growth.

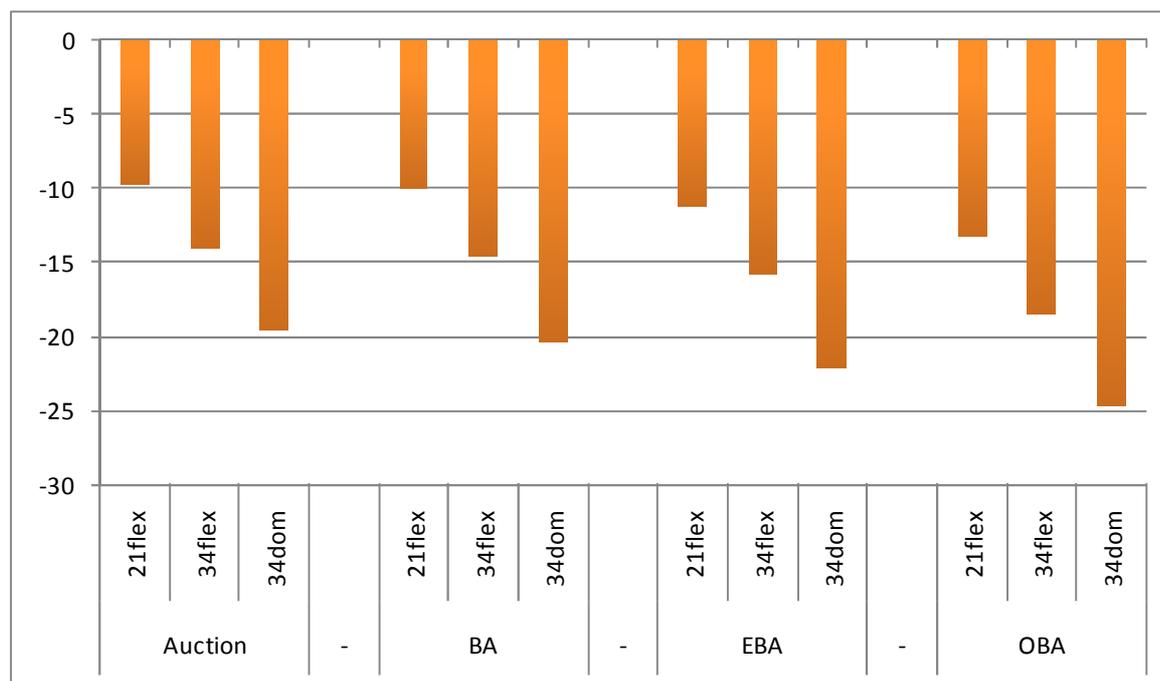
When the economic growth rate is assumed to be higher, more emissions reductions are required to meet any given emissions constraint, these mainly come from more reductions in specific emissions which leads to a larger increase in the electricity price.

Figure 10. Electricity sector: price, production, specific emissions and total emissions in the low-growth scenarios (% variation/BAU)



The specific emissions correspond to the average CO₂-contents of the kWh. As is apparent in Figure 10, *OBA* leads to the biggest decrease of the average CO₂-contents of the kWh. This is due to the higher CO₂-price for this allocation mode.

Figure 11. The average CO₂-contents of the kWh in the low-growth scenarios (% variation/BAU)



3.3.2. Steel

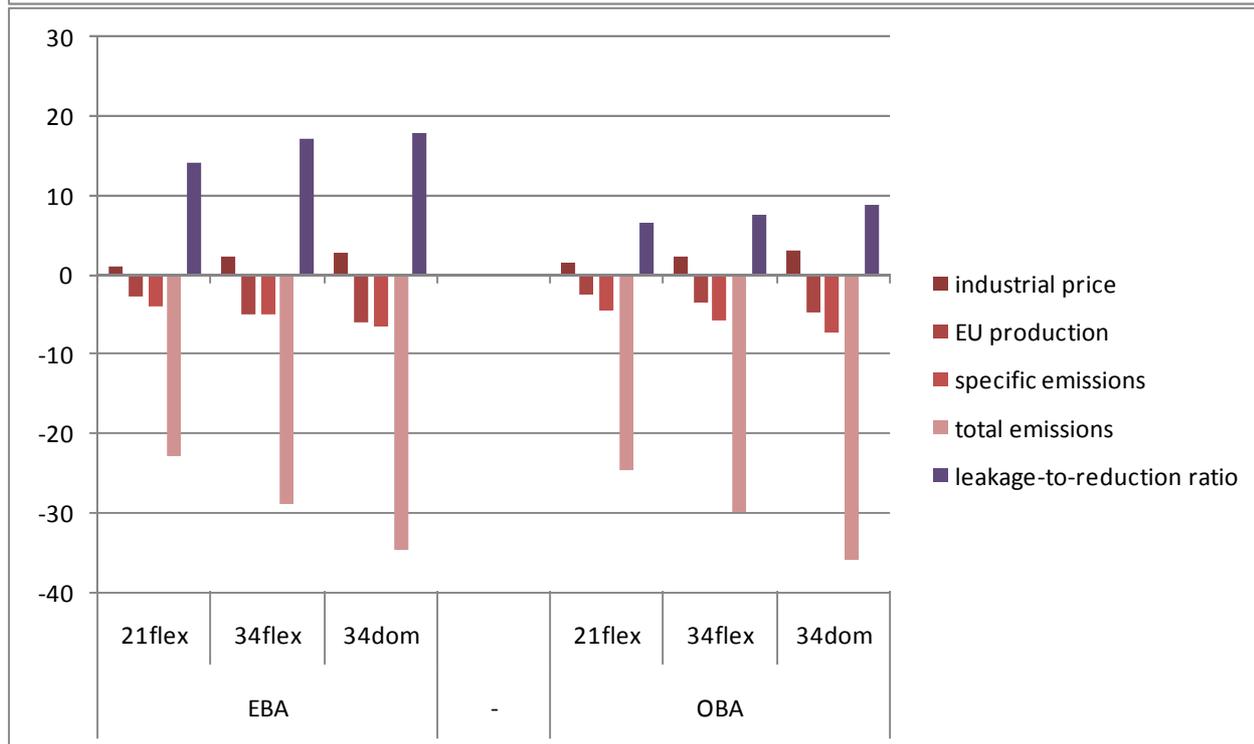
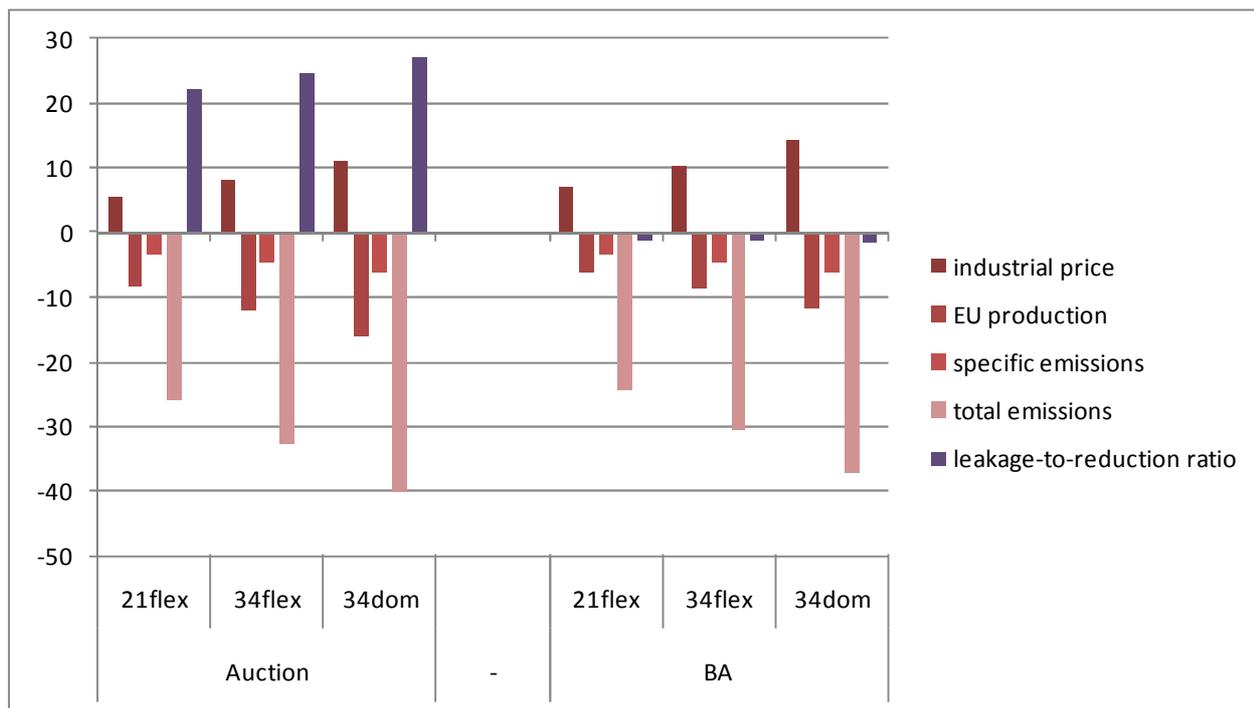
Figure 11 displays, for steel, the price index for EU consumers¹², EU production, specific and total emissions evolution and the leakage-to-reduction ratio. The price index rises slightly more under the *BA* scenarios than under *Auction*, both because of the higher CO₂ price and because the *BA* raises the price of steel imports. However, the fall in production levels is lower under the *BA* scenarios since EU producers lose less market shares vis-à-vis the RoW. Moreover, the results differ a lot in terms of the leakage-to-reduction ratio: positively in *Auction* scenarios and negatively in the *BA* scenarios. The negative leakage is due to a decrease in foreign imports into the EU and associated emissions in the RoW.

EBA and *OBA* limit the increase of the price of steel relative to *Auction* and *BA* scenarios. Consequently European steel production is reduced by less. In fact, total emissions of the sector are reduced less than under *Auction* and *BA*, even if the specific emissions are a little lower. The constraint is then met due to higher emissions reduction in the electricity sector (see 3.3.1.). This leads to a higher electricity price, which will impact the aluminium sector relatively more because of the high electricity intensity of production (see 3.3.3.). Finally, compared to *Auction* and *BA*, consumers benefit from a higher consumption of CO₂-intensive goods at a lower price with *EBA* or *OBA*.

Nevertheless, we again find that the performance to limit carbon leakage differs strongly between the two free allocation modes: the leakage-to-production ratio is divided by about 3.5 comparatively to *Auction*, under *OBA* and about 1.5 under *EBA*. This is due to a different pricing behaviour of the European firms depending on the nature of free allowance as explained in Box 1. Consequently, the European firms succeed in maintaining export levels under *OBA* (comparatively to *BAU*), while European exports are reduced (*21flex* scenario) under *EBA* on a similar scale as those in the *Auction* scenario.

¹² The price index is the weighted average of the price of domestic production and of imports.

Figure 12. Steel sector: price, production, specific emissions, total emissions and leakage-to-reduction ratio in the low-growth scenarios (% variation/BAU except for the leakage-to-reduction ratio)



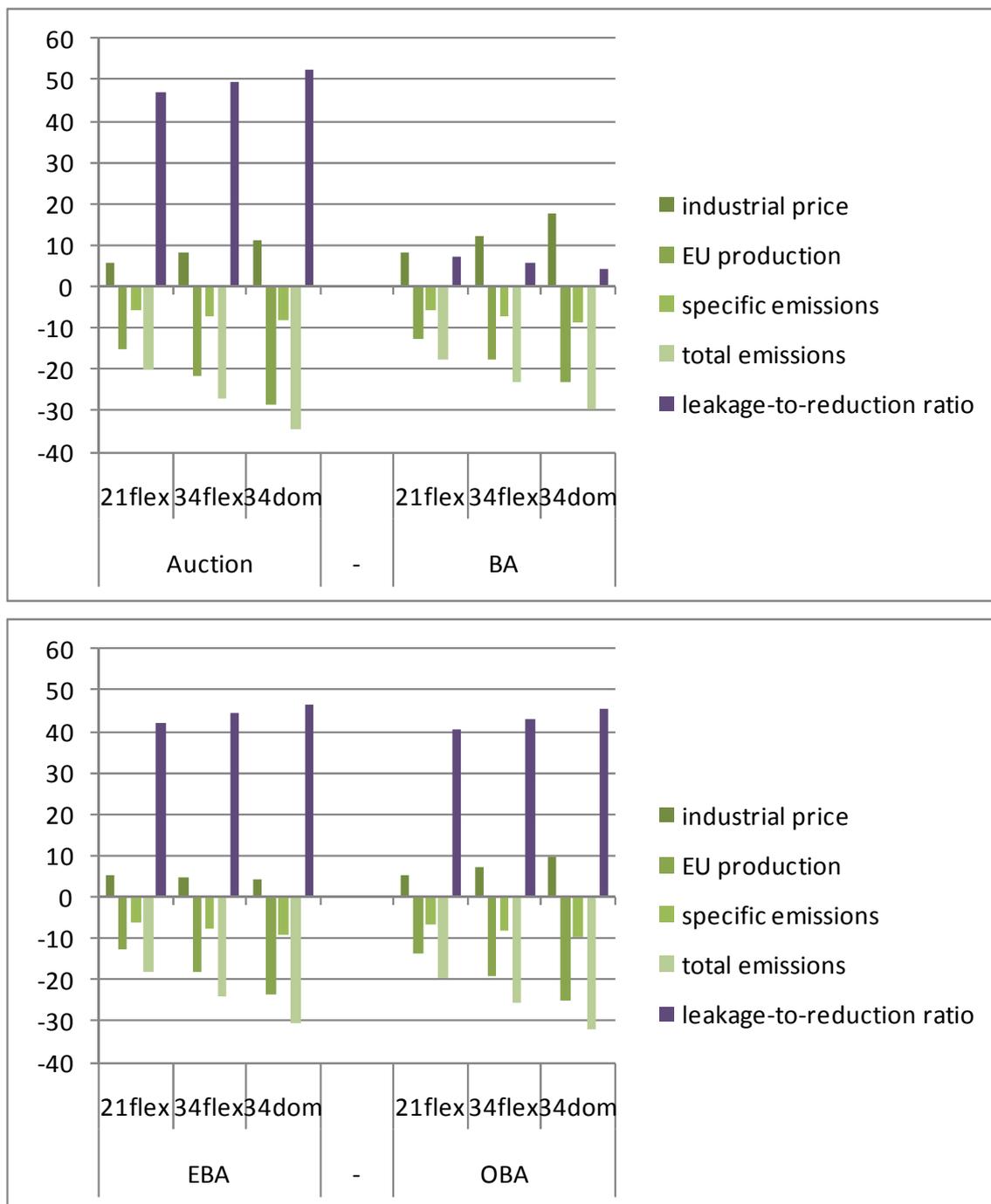
3.3.3. Aluminium

For the aluminium sector, the results differ from the steel sector mainly to the larger contribution of indirect emissions to the overall carbon costs that they face. Hence electricity price increase play a more important role. As the offsetting mechanisms to limit the carbon leakage examined target only direct emissions, the aluminium sector is hardly impacted by the CO₂-constraint. Nevertheless, the leakage-to-reduction ratio for aluminium maybe not very informative since the low value of the numerator leads to an artificially large variability. The analysis of the other variables is thus even more important for this sector for determining the sector-specific impact of different allocation methods.

Neither *EBA* nor *OBA* appears to be effective in limiting carbon leakage in the aluminium sector. This is because free allowances only compensate the impact of direct emissions, not for indirect emissions. Moreover, in these scenarios, the electricity price increases the most, which increases the production cost of aluminium, a very electricity-intensive process. Only the *BA* scenario appears to limit carbon leakage.

BA, *EBA* and *OBA* have similar performances in terms of mitigating production losses. These allocation modes also lead to a similar decline in specific and total emissions of the sector. Nevertheless, *OBA* displays the least positive results in terms of both carbon leakage and production loss.

Figure 13. Aluminium sector: price, production, specific emissions, total emissions and leakage-to-reduction ratio in the low-growth scenarios (% variation/BAU except for the leakage-to-reduction ratio)



3.3.4. Clinker and Cement

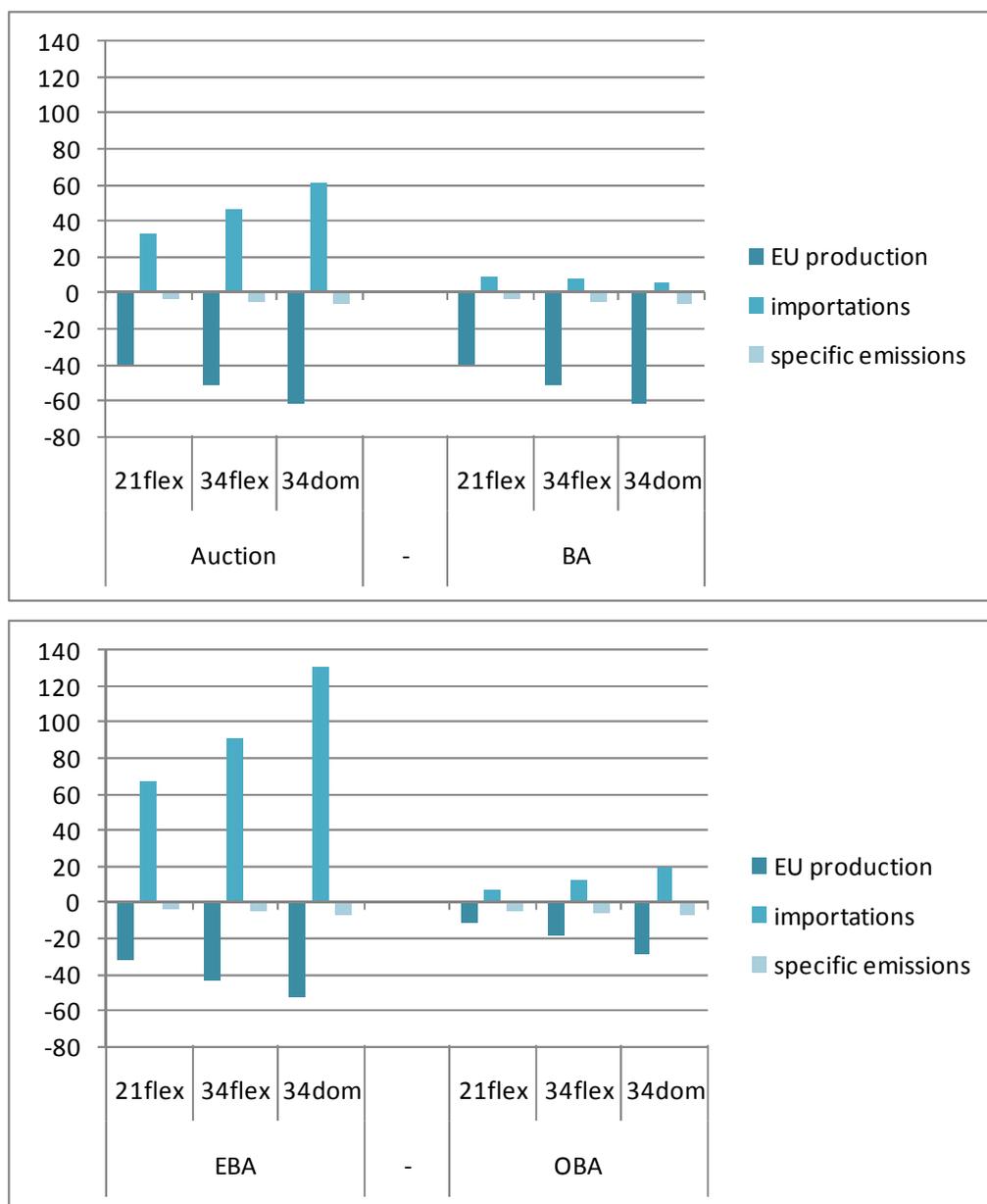
Clinker is an intermediate product to used to produce cement for which the risk of carbon leakage seems to be particularly high. Clinker has the highest CO₂ intensity among the products covered by our model and thus features the highest increase in average cost. When the CO₂-constraint is reinforced, the impact on the EU production cost is very strong, hence on the European production, which goes from -40% to -61% under Auction from 21flex to 34dom (Figure 14).

Under *EBA*, the production loss is slightly lower at -32 % (*21flex*). But only *OBA* allows really limits the collapse of European clinker production: to -11% (*21flex*) and to -18% (*34dom*). As explained in Box 1, output based allocation is related to the quantity of clinker produced. Firms are therefore incentivised to limit the imports of clinker under *OBA*, in contrast to *EBA* where we find the quantity of imported clinker is boosted.

Under *Auction* and *EBA*, clinker imports are largely used to compensate for the decline in European production. *BA* limits this substitution effect: the decrease of the European production is mainly due to the decrease in European cement consumption.

The decrease in specific emissions is very limited because 60% of clinker emissions are process emissions that cannot be cut and only limited mitigation opportunities exist to reduce the remaining 40%, which are attributed to fuel combustion. Possible important ways of cutting emissions in the cement sector is related to the use of CO₂-free substitutes for clinker.

Figure 14. Clinker: EU production, imports and specific emissions in the low- growth scenarios (% variation/BAU)



The cement price increases by less than clinker prices but more than aluminium, steel and electricity, due to its higher CO₂ intensity (Figure 15). As for steel, the rise in prices is the highest for *BA* scenarios and the lowest for *OBA* scenarios. However, the price increase under *Auction* and *BA* is much higher than in the other sectors, and the same stands for the production decrease.

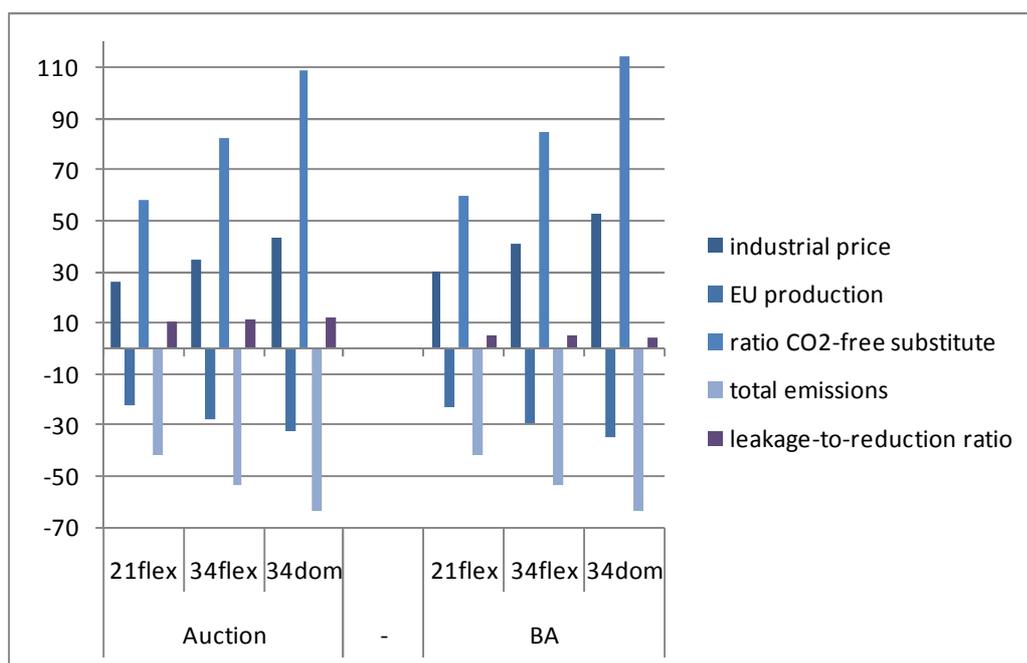
The use of CO₂-free substitute increases a lot in all the scenarios (sometimes more than doubled compared to the quantity used under the *BAU* scenarios), except for under *OBA* because European firms have the incentive to produce clinker to have free allowances.

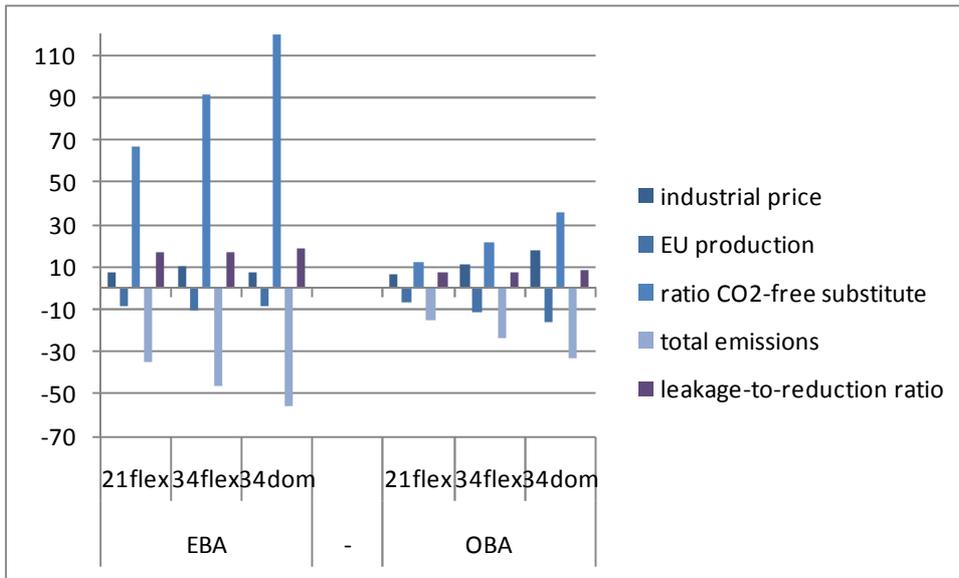
The total emissions reductions in the cement sector are reduced by less under *EBA* and *OBA*, which is also the case in the steel sector. With these allocation modes, the effort in terms of emissions reduction is more significant in the electricity sector, which tends to increase the electricity price even more.

When the emissions target is strengthened, the impact on the cement price and European production is more significant in the cement sector than in the other sectors.

Once again, *BA* appears to perform best in terms of limiting carbon leakage, followed by *OBA*. On the other hand, *EBA* induces more carbon leakage than *Auction* due to the jump in clinker importations.

Figure 15. Cement sector: price, production, specific emissions, total emissions and leakage-to-reduction ratio in the low-growth scenarios (% variation/BAU except for the leakage-to-reduction ratio)





4. Discussion and Conclusions

Does leakage have to be readdressed if the EU's target is raised beyond 20%? The simulations seem to suggest this. Carbon leakage could increase in all the sectors, however:

1. **The impacts differ depending on the sectors:** even if all the sectors are impacted by a more stringent carbon constraint or by a high-growth level, each situation will differ depending on the allocation mode implemented.
2. **There is clearly a trade-off between the sectors benefiting from free allocation and the higher emissions mitigation and prices in the electricity sector.** When allowances are given for free, higher reductions must be carried out in the electricity sector, which leads to a higher increase in the electricity price. This negatively impacts the electricity-intensive sector, like aluminium, but also feeds into increases in economy electricity prices affecting all end-users including households.
3. **The performance of the different allocation modes differ depending on the policy objective, i.e. mitigation of carbon leakage or limitation of the European production decrease.** To limit carbon leakage, the implementation of auctioning with *BA* is the best option, whichever the sector and this scenario will also limit the increase in electricity prices. But, European production levels would drop due to the decrease of the European consumption as a reaction to higher product prices. *OBA* could be an interesting compromise to limit both carbon leakage and production loss but only insofar as the abatement potentials exist. Moreover, *OBA* does not incentivise cement firms to replace clinker by CO₂-free substitutes, which is an important option to reduce the emissions in the cement sector. This incentive could also be created in other sectors which have not been modelled in this paper such as the chemical industry.
4. **The more important the ambition of the policy, the more the instrument implemented must be designed with care.** For instance, some stages of the production chain are particularly sensitive and could lead to a large increase of the leakage when carbon constraint is more stringent. For instance, in the cement sector, under free allocation based on past emissions (*EBA*), the more the CO₂ price is increased, the more the leakage will come from imported clinker. Moreover, some allocation modes depend mainly on the availability of specific emissions abatement. This consideration is more important when economic growth rates are high.
5. **More flexibility with a larger amount of international credits authorized is an option to soften these impacts but in a limited way.** If the objective is to limit the carbon leakage, *BA* is more efficient than other allocation modes, even if the international credits use is not authorized (*34dom*).

Annex I: Technical description of how cement is modelled

The proportion of clinker used to produce cement in the EU, Sh^{CK} , and the market share of imported clinker in the EU, $Sh_{EU,RoW}^{CK}$, are modelled through nested logit functions¹³:

$$Sh^{CK} = \frac{(TC_{EU}^{CK})^{-\eta_1}}{(TC_{EU}^{CK})^{-\eta_1} + (TC_{EU}^{SUB})^{-\eta_1}} \quad Sh_{EU,RoW}^{CK} = \frac{(TC_{EU,RoW}^{CK})^{-\eta_2}}{(TC_{EU,EU}^{CK})^{-\eta_2} + (TC_{EU,RoW}^{CK})^{-\eta_2}}$$

Where $TC_{EU}^{CK} = Sh_{EU,RoW}^{CK} \cdot TC_{EU,RoW}^{CK} + (1 - Sh_{EU,RoW}^{CK}) \cdot TC_{EU,EU}^{CK}$

TC_{EU}^{CK} and TC_{EU}^{SUB} represent, respectively, the total cost of using clinker and CO₂-free substitutes (flying ashes, blast furnace slag...) in EU cement production. $TC_{EU,EU}^{CK}$ and $TC_{EU,RoW}^{CK}$ represent, respectively, the cost of using domestic and imported clinker to produce cement in the EU and η_1 and η_2 are positive parameters that represent the responsiveness of Sh^{CK} and $Sh_{EU,RoW}^{CK}$ to the changes in the relative costs.

The logit functional form conserves the mass, which is a great advantage over a constant elasticity of substitution (CES) function since we want to represent physical quantities of cement. In the logit function representing the choice between clinker (either imported or domestic) and possible substitutes, the parameters are calibrated to represent the share of substitutes in cement in 2006 (23%) and an *ad hoc* assumption that doubling the cost of clinker, other things equal, would entail the doubling of the share of substitutes in cement. In the logit function, representing the choice between domestic and imported clinker, the parameters are calibrated to represent the share of imported clinker in 2006 (6%) and, to fit the following result from GEO-CEMSIM, a detailed geographic model of the world cement industry featuring transportation costs and capacity constraints with a CO₂ price of €20, the share of imported clinker doubles (Demailly and Quirion, 2006).

¹³ Such functions are used in hybrid energy-economy models such as CIMS (Murphy et al., 2007) and IMCALIM-R (Crassous et al., 2006).

Annex 2: Description of the model

Consumption

In each region $r = \{EU, RoW\}$, the representative consumer is assumed to have a two-tier utility function. The upper tier is a (logged) Cobb–Douglas function of the utility derived from consuming the goods produced by each industry, giving rise to fixed expenditures shares (a_r^i) out of income (Y_r):

$$U_r = \sum_{i=\{C,A,S,E\}} \alpha_r^i \ln(u_r^i) + \left(1 - \sum_{i=\{C,A,S,E\}} [\alpha_r^i] \right) Z_r \quad (1)$$

where a_r^i is the expenditure share of the region r in industry i , u_r^i is the sub-utility from the consumption of the varieties produced in the industry i and Z_r represents the consumption level of the good. Indexes C , A , S and E represent cement, aluminium, steel and electricity respectively.

Expenditures in region r in goods produced by industry I are then $\alpha_r^i Y_r$. We assume that the expenditure parameters stay constant between 2006 (year used to calibrate the model) and 2020 (year used for the simulations of the business as usual and the different climate policies). GDP Y_r is exogenous and growing.

In turning to the lower-tier of the utility function, we examine expenditures allocation in the industries C , A and S , each consisting of a domestic variety and a foreign variety.¹⁴ The sub-utility u_r^i is a constant elasticity substitution (CES) aggregate of the two varieties. The representative consumer has different preferences over varieties depending on their places of production, allowing in particular for home bias. This preference parameter in region r for the domestic variety is denoted $pref_{rr}^i$ while the preference parameter for the imported variety is denoted $pref_{r'r}^i$, where r and $r' = \{EU, RoW\}$ and $r' \neq r$. The sub-utility function is then:

$$u_r^i = \left((pref_{rr}^i \cdot Q_{rr}^i)^{(\sigma_i-1)/\sigma_i} + (pref_{r'r}^i \cdot Q_{r'r}^i)^{(\sigma_i-1)/\sigma_i} \right)^{\sigma_i/(\sigma_i-1)} \quad (2)$$

Where $i = \{C, A, S\}$, Q_{rr}^i (resp. $Q_{r'r}^i$) is the consumption level in region r of the good produced by industry i in region r (resp. r') and σ_i represents the elasticity of substitution (the Armington elasticity) between domestic and foreign varieties in industry i .

Maximising this sub-utility function subject to expenditures and the delivered prices from the two possible product origins, we obtain the demand curves:

$$Q_{rr}^i = \alpha_r^i \cdot Y_r \frac{(pref_{rr}^i)^{\sigma_i-1} \cdot (p_{rr}^i)^{-\sigma_i}}{(pref_{rr}^i)^{\sigma_i-1} \cdot (p_{rr}^i)^{1-\sigma_i} + (pref_{r'r}^i)^{\sigma_i-1} \cdot (p_{r'r}^i)^{1-\sigma_i}} \quad (3)$$

$$Q_{r'r}^i = \alpha_r^i \cdot Y_r \frac{(pref_{r'r}^i)^{\sigma_i-1} \cdot (p_{r'r}^i)^{-\sigma_i}}{(pref_{rr}^i)^{\sigma_i-1} \cdot (p_{rr}^i)^{1-\sigma_i} + (pref_{r'r}^i)^{\sigma_i-1} \cdot (p_{r'r}^i)^{1-\sigma_i}} \quad (4)$$

where p_{rr}^i and $p_{r'r}^i$ are the delivered prices respectively of the domestic and of the foreign variety of the industry i faced by the consumers of the region r .

¹⁴ We assume that all domestic varieties are perfect substitutes for each other, as are all foreign varieties, but that domestic and foreign varieties are incomplete substitutes.

For electricity, we do not account for international trade since it is negligible at the EU level. The electricity demand in region r is then the sum of the demand from the cement, aluminium and steel firms localised in region r and of a fixed expenditure share out of income $\alpha_r^E \cdot Y_r$ from the representative consumer.

Supply

The CES specification of the representative consumer's utility has mostly been used in monopolistic competition models following Dixit and Stiglitz (1977) and Krugman (1980) where firms do not take into account the effect of their behaviour on other firms. Strategic interactions are therefore neglected, which is not very relevant for the industries analysed in this paper since they feature a small number of large firms. Consequently we explore the case where firms compete in quantities, as in a standard Cournot oligopoly. Thus, our modelling framework encompasses both the standard Cournot oligopoly (the substitution elasticity between the imported and the domestic variety tends toward infinity) and the pure competition Armington framework (if the number of firms tends towards infinity).

In the cement, aluminium and steel sectors, each firm sells in both regions. In each region, there are n_r^i domestic firms in competition. Firms are in competition regionally and, less intensively, internationally. Trade between the regions entails a constant per-unit transportation cost. Then the profit function of a firm localised in region r is:

$$\pi_r^i = (p_{rr}^i - mc_r^i) \cdot q_{rr}^i + (p_{r'r}^i - mc_r^i - tc_{r'r}^i) \cdot q_{r'r}^i - FC_r^i \quad (5)$$

where r and $r' \in \{EU, RoW\}$ and $r' \neq r$, $i \in \{C, A, S\}$, p_{rr}^i and $p_{r'r}^i$ are the delivered prices of the good produced by a firm of industry i localised in region r and sold, respectively, in region r and in region r' , mc_r^i (resp. FC_r^i) the marginal (resp. fixed) production cost of firms localised in region r , q_{rr}^i (resp. $q_{r'r}^i$) the quantity sold in the domestic market (resp. in the foreign market) and $tc_{r'r}^i$ the (unit) transportation cost from region r to region r' .

This framework allows firms to set different prices in each market. This contrasts with the Dixit-Helpman-Krugman model in which firms perceive the same elasticity of demand in each market and therefore set export prices (net of transport costs) equal to their domestic prices (Head and Ries, 2001).

Each firm sets its production for domestic and foreign markets to maximise its profit, under quantity competition with the firms of the same region and of the other region. To determine the number of firms in each region, we assume that free-entry sets profits equal to nil in both regions. At the equilibrium, all firms from the same region being symmetric, we have $Q_{rr}^i = n_r^i \cdot q_{rr}^i$ (resp. $Q_{r'r}^i = n_r^i \cdot q_{r'r}^i$).

Excluding expenditures related to the climate policy, production costs (variable and fixed) are assumed constant but differ across regions.

Calibration and simulations

The model has been calibrated on 2006 data (prices and quantities). The values of the preference coefficient and the unit transport costs are determined by the calibration and are supposed to be constant.

Concerning the values of the Armington elasticity, large differences exist across sectors and countries.¹⁵ Moreover, estimates for Europe are rare (Welsch, 2008)¹⁶. The larger the Armington elasticity, the more easily imported commodities may substitute for domestic commodities.

The strategy has been to use middle values of Armington elasticity: 2,25 for cement, 2.75 for aluminium and 3,5 for steel.

¹⁵ See Graichen et al.(2008) for a recent survey on Armington elasticity at sector level and Donnelly et al. (2004) for a recent and complete analysis made by the U.S. international trade commission for the US.

¹⁶ According to Welsch (2008), central values employed recently in studies of carbon taxation or emissions trading with respect to Europe go from 2 to 4.

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