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Quantifying the effects of reforming the EU Emissions Trading System. A computable general equilibrium analysis

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Quantifying the effects of reforming the EU Emissions Trading System. A computable general equilibrium analysis

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Abstract

This paper studies various options to support allowance prices in the EU Emissions Trading System (ETS), such as adjusting the cap, an auction reserve price, and fixed and variable carbon taxes in addition to the ETS. We use a dynamic computable general equilibrium model that explicitly allows for allowance banking and for a detailed cost-effectiveness analysis at the EU Member State level. We find that fixed and variable carbon taxes as well as an auction reserve price support initial effective carbon prices at times of low demand for emission allowances. These price-based policies re-allocate emissions over time with stronger emission reductions in early years but emission increases in later years, compared to our baseline scenario. The fixed tax induces the strongest support for effective

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CO_2 prices for early years but may induce additional abatement beyond the ETS cap due to interaction with the Clean Development Mechanism. An auction reserve price causes stronger welfare losses to new Member States compared to the tax options. We conclude that a variable tax on CO_2 emissions from fossil fuels is an efficient and feasible way to support emission allowance prices even in the case of overlapping instruments.

1. Introduction

The average 2012 price for greenhouse gas emission allowances under the European Union Emissions Trading System (EU ETS) was €7.33 per ton of CO_2-equivalent. In April 2013 it was as low as €2.70 and the current (January 2015) price is around €7. These prices are much lower than the €30 anticipated at the time the revised ETS directive was adopted (EC, 2008a). Prices are expected to remain at a low level for a long period (EC, 2014c), which has raised concerns about the functioning of the EU ETS as a useful incentive scheme to reduce carbon emissions in the long run. In itself, a low CO_2 price is not problematic for the purpose of reducing greenhouse gas emissions: as long as emissions are covered by allowances, cumulative emissions will meet the emission reduction target ('cap'). However, the purpose of the EU ETS is also to provide a sufficiently strong price signal to stimulate long-term investments in low-carbon technologies.[2] This is one of the reasons why the European Commission (EC) has started a discussion about reforming the EU ETS in such a way that higher prices and stronger incentives to invest in clean technologies, will result (EC, 2012b).

Several design features of the EU ETS are responsible for the lower than expected carbon price (EC, 2014c). First, supply of emission allowances in the EU ETS cannot be changed within a given trading period. However, due to the economic stagnation that has hit the EU since the end of 2008, demand for allowances is much lower than expected, which partly explains the lower than expected carbon price. Second, other policy measures, such as the use of the Clean Development Mechanism (CDM) and Joint Implementation (JI), as well as the rapid implementation of renewable energy to achieve the 20% target by 2020, interact with the EU ETS. CDM/JI projects increase the supply of allowances through a system of transferable credits, while the increase in the use of carbon-free technologies such as solar photovoltaic cells and wind turbines reduces demand. Both have a downward effect on allowance prices. The third but far from least important design feature is the banking provision, which

[2] Creating a 'carbon price signal necessary to trigger the necessary investments' is one of the considerations mentioned in the 2009 revision of the ETS directive EC, 2009. Directive 2009/29/EC of the European Parliament and of the Council amending Directive 2003/87/EC so as to improve and extend the greenhouse gas emission allowance trading scheme of the Community. European Commission, Brussels.

allowed firms to bank allowances left over from the second ETS trading period (2008-2012) and use them in the third trading period (2013-2020).[3]

Environmental policy governed by principles of cost-effectiveness lies at the core of the EU ETS, so one could argue that a low price for EU Allowances (EUAs) is in itself not a sign of an ill-functioning market. Instead, the low price signals the low cost of achieving the cap: as levels of economic output are lower than expected ex ante (EC, 2008b), the planned emission reductions can be achieved at lower than expected cost. Still, many policy makers and environmental advocates perceive the current allowance price as too low and propose to adjust the cap in order to push the price up. If policy makers implicitly target some allowance price level, the cap requires adjustment after every (major) unexpected economic event, such as macroeconomic developments or a rise or fall in the oil price. Instead of regular ad hoc adjustments of the cap, structural changes to the EU ETS could be made to make the system more robust to external shocks. It has indeed been shown that cap and trade systems can be improved by allowing for (automatic) adjustments that capitalise on new information (e.g. Fell et al., 2012). As such, the robustness of the EU ETS against unforeseen economic developments (such as changes in marginal abatement costs stemming from a recession), new scientific insights, and the arrival of new technologies, could be improved. Indeed, several cap-and-trade systems that are emerging in other parts of the world include provisions to deal with such uncertainties (World Bank, 2014).

In this paper, we study how various options to reform the current design of EU ETS affect carbon prices, greenhouse gas (GHG) emissions and compliance costs, and their robustness against unexpected economic shocks. We focus on the reform options originally put forward by the European Commission (EC, 2012b) as well as on various proposals to deal with potential inefficiencies of cap-and-trade programmes discussed in the literature (Hepburn, 2006; Pizer, 2002; Roberts and Spence, 1976; Vollebergh et al., 1997; Wood and Jotzo, 2011). More specifically, we first study the effects of two policy options that reduce the number of allowances. These reform options aim to increase the carbon price indirectly through a steeper than announced decline in the number of allowances issued every year (tightening the cap) and by cancelling a given number of EUAs respectively. We then study the effects of changing the current cap-and-trade instrument into a hybrid instrument, i.e. a tailored combination of a quantity instrument and a price instrument. In particular, we analyse the introduction of an auction reserve price (while a significant number of permits is still allocated for free) as well as a combination of the EU ETS with a variable CO_2 tax on fossil fuels (for the energy sector only and for all ETS sectors, respectively) that keeps the effective carbon price at a minimum level for the sectors involved (price floor). Finally, we study the effect of a fixed EU-wide CO_2 tax on fossil fuels

[3] The transition from the second to the third trading period also increased allowance supply in 2012 with early auctioning of 120 million allowances of the third trading period in 2012 and selling part of the 300 million allowances held in the new entrants reserve of the third trading period to provide funding for the support of innovative technologies (NER300).

consumed by ETS sectors in co-existence with the EU ETS. Other cap-and-trade systems in the world already have mechanisms to support allowance prices: both the Regional Greenhouse Gas Initiative in the North-eastern United States and the joint cap-and-trade program of California and Québec have a minimum price at auctions. Moreover, price floors (and ceilings) for emission trading have a sound scientific basis (e.g. Roberts and Spence, 1976).

To study the effects of these policy options, we employ the multi-country multi-sector computable general equilibrium (CGE) model Worldscan.[4] WorldScan is well-suited to evaluate (EU) climate policy measures as it includes the segmentation of the EU economy in ETS and non-ETS sectors, allows for interactions with renewable energy policies, and takes effects on competitiveness and trade into account (Boeters and Koornneef, 2011; Bollen and Brink, 2014). Moreover, a breakdown of the EU in multiple countries allows for an explicit modelling of the quantities of emission allowances that are auctioned or allocated for free by each Member State and to study compliance cost at the Member State level. We extend our recursive dynamic model to allow for banking, but – mimicking the EU ETS – not borrowing. Banking is an essential feature of EU ETS (see Ellerman et al., 2010) and has a strong impact on the effectiveness of the reform proposals. We allow for forward-looking firm behaviour on the permit market while the cumulative number of allowances is treated as a non-renewable resource with allowance prices growing at the discount rate (Cronshaw and Kruse, 1996; Rubin, 1996). Accordingly, the effects of ETS reforms on the initial allowance price in our model will be determined by current as well as future demand and supply of allowances. We introduce this feature of the permit market in the WorldScan model and take the existing stock of about 2 billion banked permits explicitly into account. To our knowledge, this is the first paper that studies the effects of a price floor in the EU ETS on emission prices, emission levels and welfare. Furthermore we are not aware of other studies that allow for banking on the market for EU emission allowances, let alone allow for forward-looking behaviour on this market.

We find that introducing a price component to the ETS can structurally support carbon prices within the EU ETS, while tightening the cap is only an ad hoc fix, not robust to, for instance, future recessions. Introducing a carbon tax or auction reserve price initially increases the effective carbon price for the sectors affected and leads to strong initial emission reductions. Interestingly, the auction reserve price induces higher compliance cost for newer Member States, which is likely to make political implementation difficult. Our results suggest that a variable CO_2 tax is a better reform option to structurally reform EU ETS because a tax creates a robust carbon price floor without uneven welfare losses across Member States.

[4] CGE models are widely used to assess the impacts of (EU) climate policy Böhringer, C., Fischer, C., Rosendahl, K.E., 2014. Cost-Effective Climate Policy Design: Size Matters. Journal of Environmental Economics and Management 67, 318-339, Böhringer, C., Rutherford, T.F., Tol, R.S.J., 2009b. THE EU 20/20/2020 targets: An overview of the EMF22 assessment. Energy Economics 31, Supplement 2, S268-S273, Carbone, J.C., 2013. Linking Numerical and Analytical Models of Carbon Leakage. American Economic Review 103, 326-331..

The outline of the rest of this paper is as follows. Section 2 briefly describes the development of the demand for EU emission allowances since 2008 and the policy options for EU ETS reform studied in this paper. Section 3 presents the structure of the model underlying our numerical simulations. The numerical results are presented in Section 4. We test the robustness of each option towards future recessions in Section 5. In Section 6 we study interaction with renewable energy policy. In section 7 we present a summary and discussion of our findings.

2. EU ETS developments and reform proposals

This section provides some background information on the basic characteristics of the market for EU emission allowances during phase II (2008-2012) and the transition to phase III (2013-2020). Accordingly, the low price for EUAs is put in its proper context, i.e. the development of relevant markets as well as the banking provision. Subsequently we relate the reform options for the EU ETS as identified by the EC and evaluated in this paper to the relevant economic literature.

2.1 Background: supply, demand and EUA prices in phase II of EU ETS

To better understand the current oversupply of allowances, one has to take stock of the key features of the EU allowance market since the second trading period of the EU ETS, which started in 2008 (Ellerman et al., 2010). Phase II started with prices between €20 and €25 per ton of CO_2 and policymakers expected the price to rise. However, three design features of the EU ETS have caused the current price to be much lower than expected. First, with current regulation, the annual supply of allowances from free allocation and auctions is fixed while the EUA price is set by demand and supply. As can be seen in Table 1, total initial allocation of allowances in phase II increased over time. Since the demand for allowances was lower than expected and decreased over time (largely due to the 'Great Recession' that started in 2008), downward pressure on the EUA price occurred. Second, other policy measures interact with the EU ETS. Firms cannot only hand in EUAs, but can – to a certain maximum – also use credits from CDM and JI, which increases effective supply: in 2012 these credits accounted for 17% of total supply of allowances. In addition the EU ETS interacts with the EU's renewable energy policies: the rapid implementation of renewable energy as part of the EU target of 20% renewable energy by 2020 reduced demand for allowances relative to the case without such policies. These policy interactions hence caused further downward pressure on EUA prices. The third important design feature is the banking provision. Introduced in phase II, it allows firms to use allowances in the following trading period. Since cumulative total supply in phase II was 2,095 credits higher than cumulative demand, these allowances were banked and phase III started with a surplus equal to about a year's worth of emissions (see Table 1).

Table 1. Supply and demand for EU ETS allowances and CDM/JI credits in phase II[a]

	2008	2009	2010	2011	2012	Total
Free allocation	1,959	1,975	1,998	2,017	2,050	9,998
Auctions	53	79	92	93	125	442
Total initial allocation	*2,012*	*2,054*	*2,090*	*2,110*	*2,175*	*10,440*
Credits CDM and JI	84	81	137	254	504	1059
NER300[b]				12	188	200
Early auctioning[c]					90	90
Total supply	**2,095**	**2,134**	**2,227**	**2,375**	**2,957**	**11,789**
Emissions	**2,120**	**1,880**	**1,939**	**1,904**	**1,867**	**9,709**
Surplus	**-24**	**255**	**288**	**471**	**1,090**	**2,079**

[a] Data in million tonnes of CO_2 excluding international aviation.

[b] 300 million allowances held in the new entrants reserve of the third trading period, i.e. allowances put in a reserve for new installations that enter the ETS, are sold to provide funding for the support of innovative technologies. Part of these NER300 allowances were sold in 2011 and 2012 (EIB, 2012).

[c] The EC decision on early auctioning allowed for a maximum of 120 million allowances of the third trading period to be auctioned before 2013.

Source: EEA (2014), EC (2012a), EIB (2012) and own calculations.

he market for EUAs seems to have learned only at a relatively late stage in phase II that a substantial surplus of allowances had been built up. While the 'Great Recession' caused the EUA price to halve in the course of 2008, it remained stable around €14 up to mid-2011. When fears of a 'double dip' in economic output became real, the price started to decline further: below €7 by the end of 2011 and below €3 in April 2013.

It is important to note that the banking provision had opposite effects on prices in the final years of phase II and at the start of phase III. Had banking not been allowed, prices at the end of phase II would have been much lower (perhaps close to zero, as at the end of phase I) as there were many more permits available than required. However, while the banking provision supported the price at the end of phase II, it increased the total number of allowances available for phase III and hence causes the current price to be lower compared to a situation without the banking provision. Of course, the banking provision was introduced precisely for this reason: it allows for smoothing of EUA prices over time and increased intertemporal efficiency of the system as firms can reduce emissions during times in which this is cheapest.

Despite the fact that the allowance surplus at the start of phase III covered the emissions of about one year, the price for EUAs was still strictly positive: the EUA price has been hovering around €5 per ton in the second half of 2013 and most of 2014 and is currently around €7. Individual traders seem to choose to hedge against expected future scarcity (Neuhoff et al., 2012) as firms can use banked allowances beyond 2020. Still, the current lack of scarcity of allowances and its associated low price has caused a debate in the EU as to whether reform of the EU ETS is warranted and, if so, what type of reform would be best to support the EUA price.

2.2 Discussing reform of the EU ETS

The large oversupply mirrored in the low price for EUAs is not problematic for the purpose of reducing emissions. Indeed, enforcement of the cap ensures that cumulative emissions will not exceed cumulative supply of EUAs. However, as mentioned in the introduction, a low carbon price may provide little incentive to currently invest in low carbon technologies, which might make it harder for the EU to meet its 2050 emission reduction goals (e.g. Grubb, 2012). According to this view the current low price of allowances indicates a malfunctioning market which might even stand the EU in its way to reach the 2050 carbon reduction goals.

One response to an unexpected drop in demand is to tighten the cap. This, however, is only an ad hoc fix as the system is still not able to respond automatically if new unexpected events occur. Ideally, the design of emission trading systems like EU ETS should allow for automatic adjustments in response to unforeseen economic developments, new scientific insights, and the arrival of new technologies.[5] One way to implement a more flexible design is to reform the quantity-based system of emission allowances into a mixed or hybrid system. Roberts and Spence (1976) show that a system of cap and trade together with effective maximum and minimum allowance prices is preferable over the use of a single instrument when marginal abatement costs are uncertain. Expected social costs, i.e. the sum of environmental damages and abatement costs, are lower with a hybrid system because the cap protects society against very high levels of pollution while a pollution tax provides a residual incentive to abate if abatement costs are low.

Roberts and Spence (1976) propose a subsidy on permits that are handed in beyond what's required to cover the firm's emissions, rather than a tax on emissions. While this functions as a price floor, it may lead to adverse dynamic effects due to increased output at the industry level (Baumol and Oates, 1988, pp. 211-234). Burtraw et al. (2010) suggest to use a price floor at auctions to avoid such adverse effects. Wood and Jotzo (2011), however, argue that the best way to implement a price floor in a cap and trade system is through an emissions fee. This fee comes on top of the permit price and can either be fixed or variable. In the latter case a minimum level of the sum of the fee and the permit price can be set such that the price floor is constant.

[5] Kelly and Vollebergh Kelly, A.J., Vollebergh, H.R.J., 2012. Adaptive policy mechanisms for transboundary air pollution regulation: Reasons and recommendations. Environmental Science & Policy 21, 73-83. summarize these arguments in relation to the inflexibility of the present EU air quality policy, drawing from the wide experience with tradable permits under US SO_2 and NO_x trading schemes.

In recent years the EC has floated several ideas for adjusting the EU ETS. The most recent proposal by the EC to support the EUA price is to tighten the cap by increasing its annual reduction (EC, 2014d). In addition, the EC has proposed to introduce a market stability reserve: if the surplus of allowances in the market is sufficiently large, part of the supply of allowances will be added to a reserve rather than auctioned.[6] These allowances will not be released from the reserve until scarcity on the permit market has increased (EC, 2014c). By reducing the supply of allowances the EC intends to mitigate the fall in the EUA price in times of oversupply. Both reform proposals take a 'single instrument approach', i.e. an approach in which no new instrument is used to address the environmental problem. Earlier reform proposals within this single instrument approach include postponement of the allocation of allowances ('backloading', EC, 2012a; EC, 2014a) or even cancellation of allowances, extension of the scope of EU ETS to other sectors, and limitation of the use of CDM and JI credits (EC, 2012b).

The EC has also put forward a price floor and a price management reserve (each of which would transform the EU ETS from a quantity instrument into a hybrid instrument) as options to reform the EU ETS (EC, 2012b). These hybrid instruments did not get much support in the consultation of stakeholders. They generally highlighted that EU ETS is an instrument based on volume not on price. Consequently, the EC did not include any price management mechanism in its proposal (EC, 2014c).[7] Other hybrid instruments, such as tailored combinations of different instruments, in particular carbon taxes with tradable permits, have never been on the table in the discussion on EU ETS reform. Instead the EC advocates a policy that avoids overlap of instruments.[8] The UK, on the other hand, did introduce a carbon price floor, which is made up of the EUA price and an additional tax on fossil fuels for electricity generation (HM Treasury, 2011, 2014).

Based on these policy options and the economic literature, we evaluate the effects of the following adjustments of EU ETS:

1. *TCAP*: a tighter cap through a stricter linear reduction factor for the number of allowances issued per year;
2. *PSA*: permanent set aside of EUAs;
3. *AUCT*: an auction reserve price in the EU ETS;

[6] The proposed mechanism is unlikely to have much of an effect on firms' behaviour before 2030 because of the large size of the existing allowance bank and because a cap neutral adjustment of the auction timing should have a minimal or zero impact on the allowance price due to inter-temporal price smoothing Edenhofer, O., Normark, B., Tardieu, B., 2014. Reform Options for the European Emissions Trading System (EU ETS).. As we focus on market developments up to 2030, the effects of the Market Stability Reserve are beyond the scope of this paper.
[7] Currently, the EC has (limited) possibilities to mitigate *high* EUA prices through Article 29(A), which allows member states to bring forward the auctioning of some of the EUAs to be auctioned or to auction up to 25% of the remaining New Entrants Reserve. In addition, the non-compliance penalty of €100 acts as an ultimate price ceiling. Still, the EC has no possibilities to increase or support prices.
[8] For instance, the proposal for the European Energy Tax Directive exempts ETS sectors from the carbon component of this tax EC, 2011b. Proposal for a Council Directive amending Directive 2003/96/EC restructuring the Community framework for the taxation of energy products and electricity. European Commission, Brussels..

4. *VTAX*: a variable tax on CO_2 emissions from fossil fuels in addition to the CO_2 price from EU ETS:
    a. *VTAXpow*: the variable tax only applies to the power sector;
    b. *VTAXall*: the variable tax applies to all ETS sectors;
5. *FTAX*: a fixed tax on CO_2 emissions from fossil fuels for ETS sectors, in addition to the CO_2 price from EU ETS.

The first three options aim to improve the functioning of the EU ETS by defining improvements within the system itself. The final three policy options introduce a price component in addition to the CO_2 price from the EU ETS using another instrument, i.e. a carbon tax. All options aim to structurally reduce (downward) price risks in order to make investments in low-carbon technologies more attractive. We subsequently discuss each option in more detail.

1. TCAP: A tighter cap on EU ETS

Currently, the ETS cap decreases annually according to a Linear Reduction Factor (LRF) of 1.74% of the average total quantity of allowances issued annually in 2008-2012, which corresponds to an annual reduction of roughly 38 million allowances. For the policy option *TCAP*, we set the LRF at 2.52% starting in 2013, corresponding to an annual cap decrease of roughly 54 million allowances (about 2.6 billion allowances over the period 2013-2030), based on the Roadmap 2050 that describes emission reduction targets that aim to limit global warming by 2°C (EC, 2011c).[9]

2. PSA: Permanent set aside

In 2014, the EC decided to 'backload' 900 million EUAs by setting aside permits scheduled for auction in 2014-2016 and auctioning them in 2019-2020 (EC, 2014a). For the policy option *PSA*, we assume that the allowances set aside are not backloaded but permanently cancelled, leading to a reduced cumulative allowance supply in the 2013-2020 period.

3. AUCT: Auction reserve price in the EU ETS

An auction reserve price implies that no allowances are auctioned at a price below a pre-defined floor price. Hence, if the price for allowances at the auction is below the floor price, supply of permits is decreased. For the policy option *AUCT*, we assume that allowances that are not auctioned at a price higher than or equal to €20 per EUA are kept in a reserve, to be auctioned again and sold when market

[9] The most recent proposal by the European Commission EC, 2014d. A policy framework for climate and energy in the period from 2020 to 2030. European Commission, Brussels. includes an increase in the linear reduction factor to 2.2% from 2021 onwards. This is a weaker version of our policy option *TCAP*.

participants are willing to pay at least the €20 floor price.[10] Note that since a significant number of allowances is allocated for free rather than auctioned each year, firms can purchase freely allocated allowances (as well as banked permits and CDM and JI credits) on the market for EUAs. The equilibrium price may be hardly or strongly affected by the auction reserve price, depending on the extent to which firms need to buy permits they do not purchase at auctions on the market for existing EUAs and the willingness of (price-taking) permit holders to sell part of their holdings. A minimum price for auctioned allowances could hence result in a higher and more stable CO_2 price.

4. VTAX: A variable tax on CO_2 emissions from fossil fuels on top of the EUA price

4a. VTAXpow: A variable tax for the power sector only,

A carbon price floor can also be implemented by means of a variable tax, the level of which ensures that the sum of the tax and the allowance price is higher than or equal to a pre-determined level. As mentioned before, in April 2013 the UK introduced such a tax on fossil fuels used for electricity generation (HM Treasury, 2011, 2014). In *VTAXpow* we follow the UK example and implement an EU-wide carbon tax on fossil fuels used in the power sector, on top of the EUA price. In line with the auction reserve price in *AUCT*, we set the effective minimum CO_2 price (i.e. the sum of the EUA price and the variable tax) for the power sector at €20/tCO_2.

4b VTAXall: A variable tax for all EU ETS sectors

This policy option is a variable CO_2 tax as in *VTAXpow*, but imposed on CO_2 emissions from fossil fuel use in all EU ETS sectors rather than just the power sector. This results in a minimum effective CO_2 price for all ETS sectors of €20 per tonne.

5. FTAX: Fixed tax on CO_2 emissions from fossil fuels for ETS sectors on top of the EUA price

This policy option assumes the introduction of a fixed (rather than variable) tax on CO_2 emissions from fossil fuels for all ETS sectors in coexistence with EU ETS.[11] Hence, in equilibrium, marginal abatement costs are equal to the *sum* of the tax and the CO_2 price from EU ETS. Note that, in a deterministic model like WorldScan, the tax will fully crowd-out the permit price: permit prices are positive only when equilibrium marginal abatement costs are higher than the tax while the cap is binding. In line with *VTAX*, we assume a tax rate of €20/tCO_2.

[10] This price is lower than the €30 anticipated by the EC in 2008, yet significantly higher than the current EUA price. We present robustness checks with prices of €15 and €25 in section 5.

[11] We restrict the tax to emissions from fossil fuels because the EU already has rules on energy taxation whereas extending the tax beyond energy (e.g., cement and non-CO_2 gases) would require changes in EU fiscal policy.

3. Model structure and model calibration

3.1 Model structure: production technologies and allowance banking

We quantify the effects of temporary fixes and structural reform options of the EU ETS on carbon prices, GHG emissions and compliance cost using WorldScan, a global multi-region multi-sector recursively dynamic CGE model (Boeters and Koornneef, 2011; Bollen and Brink, 2014; Lejour et al., 2006). Multi-region, multi-sector CGE models are widely used to assess the impact of (EU) climate policies, as these models allow to analyse the impact of climate policy through complex substitution, output and income effects that result from changes in relative prices, while taking into account that countries are heterogeneous in production and consumption (Böhringer et al., 2014; see e.g. Böhringer et al., 2009a; Carbone, 2013).

In WorldScan, production sectors are modelled using a nested structure of constant elasticity of substitution (CES) production functions. At the top level, a CES composite of intermediate goods and services is combined with an aggregate of energy, capital and labor at a very low substitution elasticity (0.01). The next level describes the substitution possibilities between the aggregate of energy carriers and value-added, for which a substitution elasticity of 0.5 is assumed (van der Werf, 2008). The energy part of the production tree is modelled by three-level nested CES-functions (Lejour et al., 2006, Figure 8.2). At the top, electricity is separated from non-electrical inputs with a substitution elasticity of 0.25. The electricity sector has a bottom-up structure with separate technologies (fossil, nuclear, biomass, wind and solar, and hydropower; Boeters and Koornneef, 2011). At the second level, coal is combined with other energy inputs with a substitution elasticity of 0.7. The lowest level of the energy nest is formed by natural gas, petroleum products and biomass with a substitution elasticity of 0.5. As in most CGE models, intra-industry trade is modelled following the Armington approach (Armington, 1969), according to which firms in each region produce a unique variety of a particular good which are considered as imperfect substitutes.

The model covers the most relevant anthropogenic emissions of greenhouse gases in relation to the combustion of fossil fuels (the main source of CO_2), but also includes emissions not directly related to energy use (e.g. CH_4 and N_2O from agricultural activities and waste disposal, and CO_2 from cement production). Moreover, WorldScan also provides a detailed linkage with air pollution emissions (Bollen and Brink, 2014).

Emission reductions can be achieved by structural changes (such as savings on the use of fossil fuels and changes in the fuel mix) as well as through emission control measures represented by marginal abatement cost curves (MACs) for emissions from each sector. These MACs were derived from data on abatement technologies from various bottom-up models such as GAINS (e.g. Amann et al., 2011) and TIMER (Van Vuuren et al., 2007), and mainly include 'end-of-pipe' abatement options (especially of non-CO_2 GHG emissions, but also carbon capture and storage), removing emissions largely without affecting the emission-producing activity itself (Bollen and Brink, 2014).

The effect of ETS reform on prices of emission allowances not only depends on marginal abatement costs, but will also be affected by the degree to which firms bank allowances for future use, both within phase III and for use after 2020. As noted before, the banking provision introduced in phase II of the EU ETS supported the EUA price at the end of phase II but led to lower prices – compared to the case without banking – at the start of phase III. In a recursively dynamic model like WorldScan, however, agents behave myopically because they are assumed to react to current prices only. Since banking is a key characteristic of current price formation in the market for EUAs, we have to adapt the model to allow firms to bank allowances. Since banking results from intertemporal optimizing behaviour given firms' expectations about future prices of EUAs, we modify our recursive dynamic model in such a way that it allows for this type of forward looking behaviour.

In order to include such forward-looking behaviour on the allowance market, we follow Cronshaw and Kruse (1996), Rubin (1996) and Ellerman and Montero (2007), and model the stock of allowances *A* as a non-renewable resource:

$$A_t + \sum_t^T a_t = \sum_t^T e_t, \tag{1}$$

where a_t denotes the number of allowances allocated in year *t* (through auctioning or free allocation), *e* denotes the level of emissions and *T* denotes the end of the model horizon. For each ton of emissions, one allowance needs to be surrendered, so the stock of allowances *A* increases if more allowances are allocated than surrendered.

The degree to which the EU ETS allows for intertemporal borrowing of permits is virtually zero. Firms receive free allocation in February each year, while permits for year t-1 must be surrendered before May. Hence, implicit borrowing is possible but limited by the amount of next year's free allocation, and impossible between phases (Trotignon, 2012). Therefore, we do not allow for borrowing in our model, which implies that the bank of unused allowances cannot become negative:

$$A_t \geq 0 \ . \tag{2}$$

Profit maximization implies that the value of allowances must be zero if firms still have unused allowances at the end of the time horizon:

$$p_T A_T = 0 \tag{3}$$

where p_T denotes the price of an allowance at the end of the time horizon. In a banking model without uncertainty and with perfect competition, the permit price grows with the rate of return on alternative assets *r* (Ellerman and Montero, 2007; Hotelling, 1931):[12]

$$p_{t+1} = p_t(1 + r_t). \tag{4}$$

[12] Similar assumptions are made in Babiker et al. Babiker, M., Gurgel, A., Paltsev, S., Reilly, J., 2009. Forward-looking versus recursive-dynamic modeling in climate policy analysis: A comparison. Economic Modelling 26, 1341-1354. to allow for banking in the recursive dynamic version of the MIT EPPA model.

3.2 Model calibration

WorldScan is calibrated using data for the base year 2004 which, to a large extent, are taken from the GTAP-7 database (Narayanan and Walmsley, 2008). This GTAP database provides integrated data on bilateral trade flows and input–output accounts for 57 sectors and 113 countries. The aggregation of regions and sectors can be flexibly adjusted in the WorldScan model. The version used here features 19 regions (eight of which are regions within the EU), 17 sectors and multiple energy technologies. The power sector is divided into five technologies: (i) fossil-fuel-fired electricity generation (using coal, oil and natural gas as imperfectly substitutable inputs), (ii) wind (onshore and offshore) and solar energy, (iii) biomass, (iv) nuclear energy, and (v) conventional hydropower (Boeters and Koornneef, 2011).[13]

The impacts of reform options are measured relative to a business-as-usual scenario (BAU), which provides baseline projections as to how the global economy evolves without any new policy interventions. This BAU builds on projections of energy and macroeconomic developments in the Current Policies Scenario of the World Energy Outlook 2011 (WEO-2011, OECD/IEA, 2011). We use basic inputs from the WEO-2011, such as growth rates for population and GDP per region, energy use per region and energy carrier, world fossil-fuel prices per energy carrier, and the shares of fossil fuel, nuclear energy, biomass, wind, and hydropower in power generation in each region. Furthermore, we use the Baseline 2009 scenario that has been developed for the EC with the PRIMES model (Capros et al., 2010) to further disaggregate the developments for the EU.

Although current legislation on the EU ETS has no explicit end date and banking beyond 2030 is likely to be allowed, we set the end of the time horizon for banking (i.e. T in equation 3) at the year 2030 in our model. Hence, we assume that companies will exhaust all EUAs and credits that become available over the time period 2013-2030, plus the surplus existing at the start of 2013, by 2030.[14]

Equilibrium allowance prices grow at the rate of return to capital (about 8% in our BAU scenario); in equilibrium, marginal abatement costs do so as well. To ensure that all permits have been used at the end of the planning horizon we ran the model for different initial values for the permit price to find the initial price that satisfies equation (3). Figure 1 shows the results of this calibration exercise for our baseline projections. At an initial price of €11.10 the stock of allowances is exactly exhausted in 2030. Setting the initial value too low, e.g. €7, leads to early exhaustion and a jump in the allowance price (in 2024, in the figure) that violates equation (4). Setting the initial value too high leads to a positive

[13] See Appendix A for more details about the model and aggregation.
[14] This assumption seems justified because large uncertainties dominate climate policies in the long term while firms apply relatively high discount rates on current investments, which reduces the incentive to bank. Indeed, we believe it is unlikely that the possibility of banking beyond 2030 will have a strong impact on firms' current behaviour.

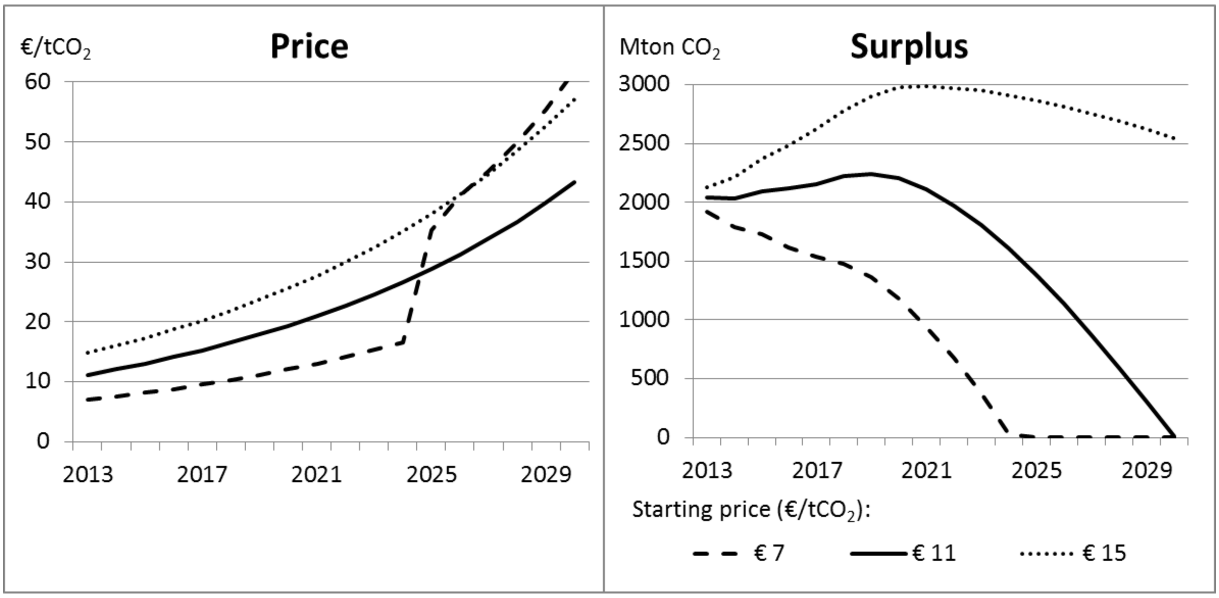

Figure 1. Effect of 2013 starting price of EU ETS allowances on surplus in the BAU scenario.

stock of allowances in 2030, which violates equation (3). We repeat this exercise for each policy scenario, resulting in different permit price paths induced by the different policies.

In our BAU scenario, we find an allowance price that starts at €11.10/tCO_2 in 2013 and rises to €19.10 in 2020 and to €42.80 in 2030. Disregarding the possibility of banking beyond 2030 has a downward effect on the EUA price as the number of allowances that will be used up to 2030 is higher relative to the case where EUAs will be banked up to later years. EUA prices in our BAU are higher than the price currently observed on the EUA market and recent projections for the price of EUAs (e.g. EC, 2014b). Apparently, demand for allowances in our BAU exceeds current market expectations. Expectations about future economic developments and fossil-fuel prices on the EUA market may differ from those in our baseline scenario. Moreover, in our model set up traders and investors are assured of an emission cap that further decreases up to 2030 and thus guarantees the value of allowances up to 2030. In the real world, however, regulatory uncertainties are likely to be larger and will keep emission prices down.

Figure 2 shows the price development as well as the development of demand and supply for permits for our BAU. After 2013, the annual supply of allowances through auctioning and free allocation declines, following current EU policy. Despite this reduction in supply, however, demand remains below annual supply until 2019 and the stock of unused allowances increases to about 2.2 billion by 2020. These developments are in line with expectations in the market that supply is likely to exceed demand up to 2020 (Egenhofer et al., 2012).[15]

[15] More details about our BAU scenario can be found in Appendix B.

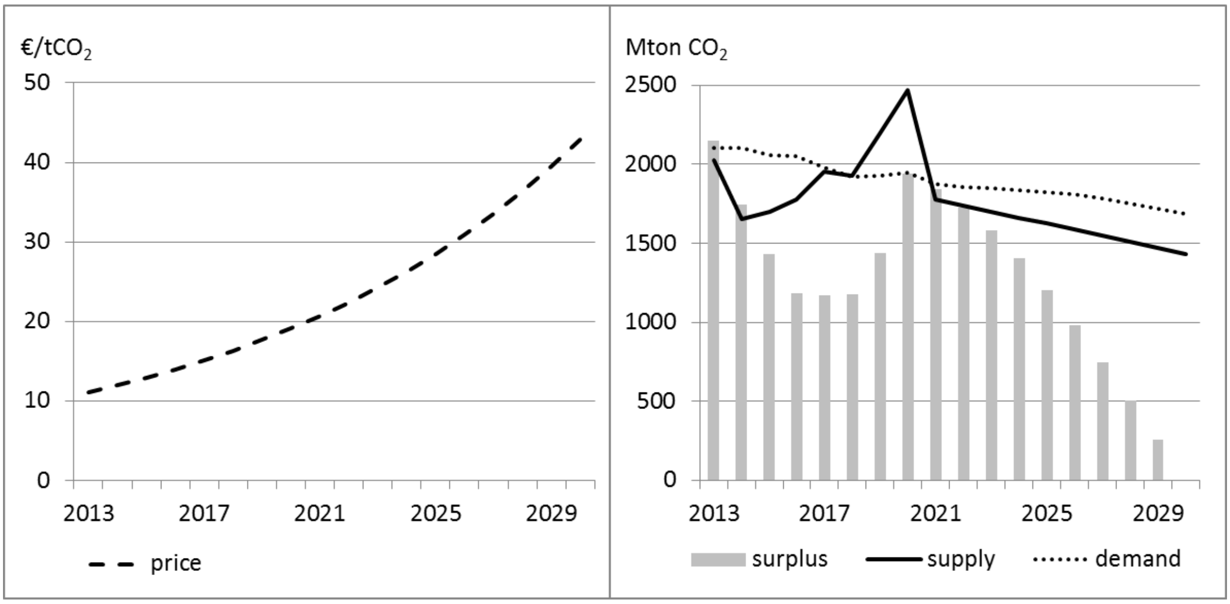

Figure 2**.** Price and surplus of EU ETS allowances in the BAU scenario

4. Results

In this section, we present the model results for the different policy options for EU ETS reform. We first present results for the effective carbon price, EUA prices, and GHG emissions. In section 4.2 we show the distribution of economic costs of each reform option across EU Member States.

4.1 Effects of ETS reform on emission prices and emissions

We first present the effects of the reform options that do not require the introduction of an additional tax. Figure 3 shows the effects of the tightening of the cap through a higher linear reduction factor (*TCAP*), the permanent set aside of allowances (*PSA*) and the auction reserve price (*AUCT*) on effective CO_2 prices, EUA prices, and GHG emissions. Contrary to the options that introduce an additional tax, the effective CO_2 price and EUA price are identical for these reform options.

All policy options show an increase in the initial effective carbon price compared to *BAU* for the sectors affected by the policy. Under *TCAP* and *PSA* – the options under which the ETS remains a pure quantity instrument – the initial increase in the emissions price is less than under the other policy options. As of 2018 (*TCAP*) and 2022 (*PSA*), however, the price is higher than under the other options as the effective CO_2 price, which solely consists of the EUA price, continuously increases at the rate of return on capital. Since both options reduce the cumulative number of allowances available over 2013-2030 (8% with *TCAP* and 3% with *PSA*, relative to *BAU*), in each year emissions are reduced more than under *BAU*.

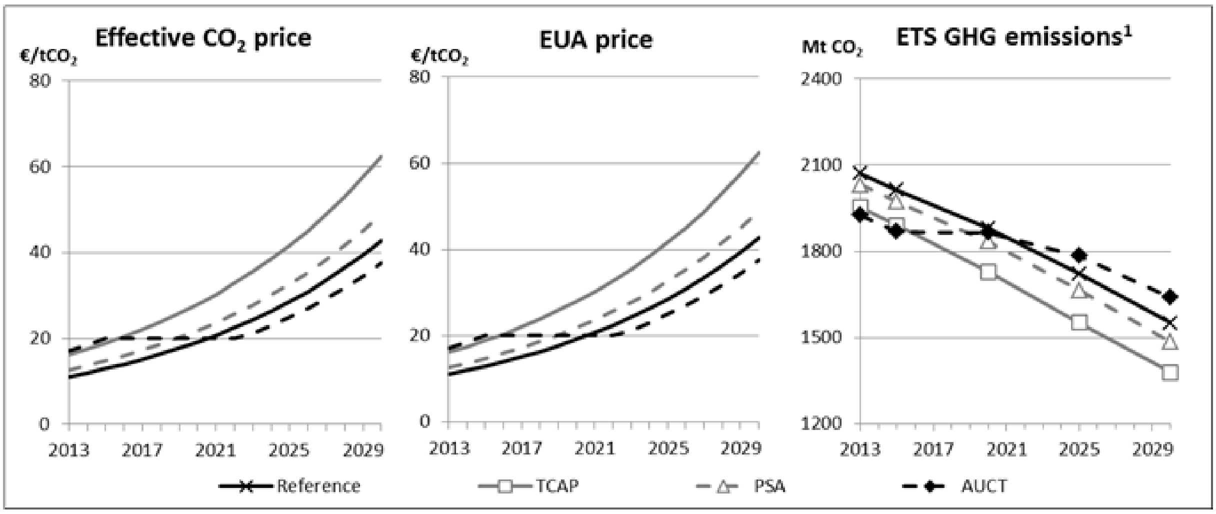

Figure 3. Effects on emission prices and ETS greenhouse gas emissions.

* Emissions include emissions from EFTA countries included in the ETS; emissions from international aviation are not included. We report emissions for the years 2013, 2015, 2020, 2025 and 2030.

With an auction reserve price (*AUCT*), EUAs are initially not sold on auctions since the reserve price is higher than the market price: even though the 2013 permit price of €17.10 is significantly higher than the *BAU* price, it is below the auction reserve price of €20. Hence, only permits that are freely allocated and permits from the stock of banked permits (and some CDM credits) can be used. As the stock of banked permits declines over time, the EUA price grows with the rate of return on capital, until it reaches €20 in 2015. From this moment onward, firms start buying at auctions again. The allowance price is equal to the auction reserve price of €20 for 2015-2022. From 2023 onward, the price starts to grow again at the rate of return such that equation (3) is fulfilled in 2030. The resulting emissions path is not continuously declining as with the options that tighten the cap. Initial emissions are lower than under *BAU* and decrease in the first two years, but are then more or less constant for five years, after which they further decrease. Contrary to the first two options, cumulative emissions are equal to those under *BAU* as total supply of allowances does not change. Hence, the emissions path crosses the *BAU* path around 2020 and from then on, emissions are higher than under *BAU*.

Figure 4 shows the effects of the reform options that introduce a tax in addition to the ETS. It is important to note that these options effectively introduce a wedge between the effective carbon price paid by firms (first panel in the figure) and the price for EUAs (second panel). With *FTAX* (the fixed CO_2 tax on fossil fuels for all ETS sectors) a tax of €20/tCO_2 needs to be paid on top of the price for EUAs. With *VTAXall* and *VTAXpow* – a variable CO_2 tax on fossil fuels for all ETS sectors and for the power sector only, respectively – a variable tax needs to be paid on top of the price for EUAs, such that the sum is at least €20/tCO_2.

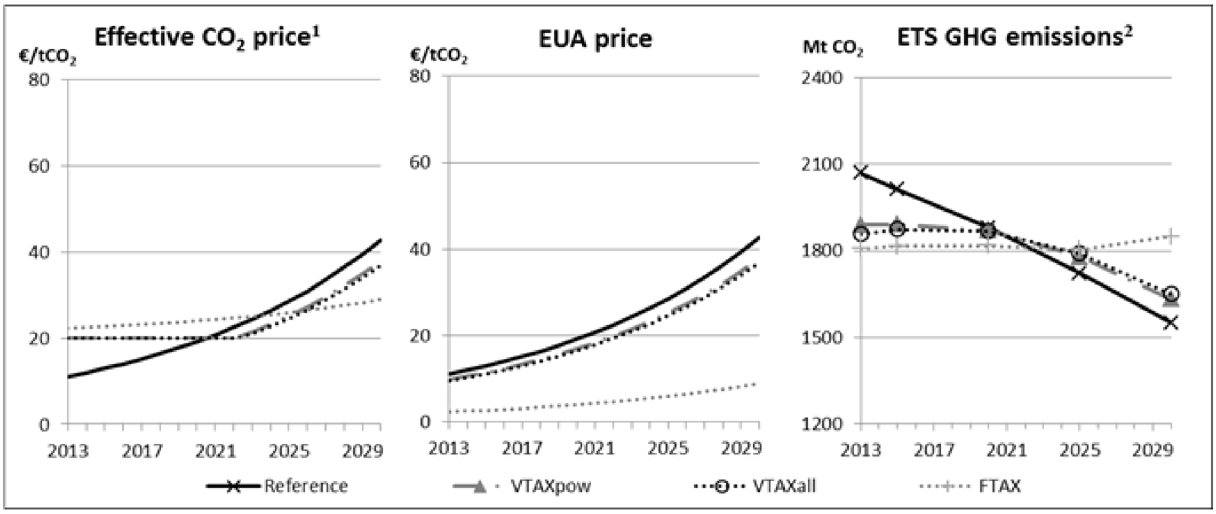

Figure 4. Effects on emission prices and ETS greenhouse gas emissions.

[1] For *VTAXpow* the effective CO_2 price applies to the power sector only; other ETS sectors only face EUA price.

[2] Emissions include emissions from EFTA countries included in the ETS; emissions from international aviation are not included. We report emissions for the years 2013, 2015, 2020, 2025 and 2030.

The initial price increases from the tax options are even larger than those under the ‘no tax’ options. The fixed CO_2 tax on fossil fuels for all ETS sectors (*FTAX*) leads to the strongest initial increase in the effective carbon price (left panel of Figure 4). The two options with a variable CO_2 tax (*VTAXpow* and *VTAXall*) also induce strong initial increases in the effective CO_2 price. With *VTAXpow*, however, it is only the power sector that faces the higher price: all other ETS sectors only face the EUA price (centre panel of Figure 4), which is initially 12% *below* the price in the *BAU* scenario.

In all three tax options, however, the difference with the *BAU* effective CO_2 price declines over time, and as of 2021 (*VTAXall* and *VTAXpow*) and 2024 (*FTAX*) the effective CO_2 price is below the *BAU* price. Since these price instruments are auxiliary to the cap, they simply reallocate emissions over time, reducing early emissions and increasing later emissions relative to *BAU* (see right panel of Figure 4). The chosen tax rate (€20) is found to be sufficiently high to induce substantial emission reductions in early years. Given the existing stock of banked permits and the development of the cap over time, this means that in later years there is quite some room for emissions. This, in turn, induces a low price for EUAs: as can be seen in the centre panel of Figure 4, with a fixed tax the price for EUAs stays below €10/tCO_2, i.e. 80% below *BAU*. In all three tax options, cumulative emissions are equal to those in the *BAU*, as the tax rate is not sufficiently high to induce cumulative emission reductions beyond what’s required by the cap. The fixed CO_2 tax (*FTAX*) induces emissions in 2030 to be 19% above the emission level in the *BAU*. Interestingly, the price and emission paths for the two variable tax options *VTAXall* and *VTAXpow* are virtually the same. The reason is that in any scenario, most emission reductions come from the energy sector.

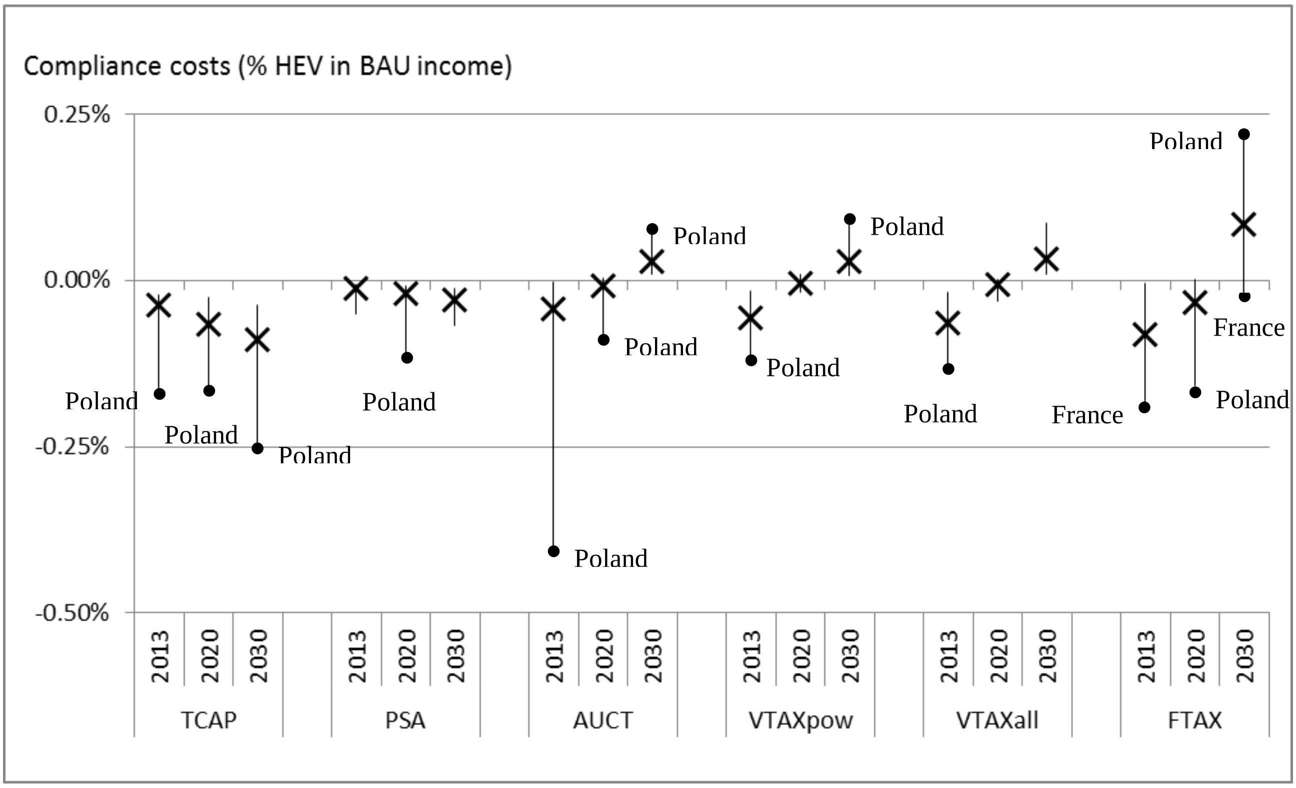

Figure 5. Compliance costs of policy options in 2013, 2020 and 2030 for EU27 as a whole (marked with cross) and for selected EU Member States (Hicksian equivalent variation expressed as percentage of national income in *BAU*; range indicates variation between individual Member States).

It should be noted that even for *FTAX* the effective carbon price grows over time: while the CO_2 tax stays constant, the EUA price grows with the rate of return on capital. The fact that with this option the 2030 effective carbon price is lowest over all options could be considered a weakness of this option, but actually reflects the strong early emission reductions stemming from the €20 additional CO_2 tax on fossil fuels.

We have now seen that all reform options induce an increase in the initial effective CO_2 price. In section 5.1 we will check how robust each option is against low economic growth. First we assess the economic costs of each ETS reform option.

4.2 Economic costs of ETS reform

Although quantity options *TCAP* and *PSA* may look appealing due to their cumulative emission reductions, the flipside of the coin is that they lead to higher costs. Figure 5 shows the compliance costs of each policy option for the years 2013, 2020 and 2030: the cross indicates the change in welfare for the EU as a whole and the vertical bar gives the range of welfare changes for Member

States.[16] Tightening the cap through a higher linear reduction factor or through a permanent set aside, induces welfare losses for all countries for all years. The other policy reforms do not tighten the cap but reallocate emissions over time. Indeed, they cause initial welfare losses and later welfare gains, following the respective emissions time path.

Since *AUCT*, *VTAXpow*, *VTAXall* and *FTAX* do not affect cumulative emissions, we can compare the welfare impacts of these options. While their impacts on the EU as a whole are comparable, they differ in their regional impacts. Notably, newer member states suffer much larger welfare losses from an auction reserve price than from the taxes, as exemplified by Poland's welfare loss in 2013 in the Figure. The newer Member States receive a relatively large share (25% for the 15 new member states as a group) of the EUAs to be auctioned, but the industry within these Member States receives only 10% of the EAUs allocated for free. As a result, new Member States are net buyers of EUAs. With an auction reserve price, no EUAs will be auctioned until 2015, which implies that even more allowances have to be bought, or more emission reductions must take place, resulting in relatively large welfare losses in early years. The two options with variable taxes lead to more evenly distributed welfare losses over the Member States, although generally welfare effects are larger for newer Member States than for the EU as a whole.

5. Implications of alternative assumptions

The current discussion to reform the EU ETS is induced by the perception of a poor performance stemming from unexpected shocks, such as lower than expected economic growth. CGE analysis enables us to explicitly test the (relative) performance of our EU ETS reform options for such unexpected shocks in the future. For this test we compare the results in the previous section, based on a *BAU* scenario with average annual GDP growth in the EU of 1.8%, with results from model simulations with different assumptions regarding economic growth. Furthermore, our CGE model allows us to test the impact of different levels of intervention stringency in the EU ETS market, i.e. the level of the CO_2 tax and auction reserve price. Different levels of stringency may induce very different impacts on emissions, prices and welfare under the various policy reform options.

5.1 Impact of the reform options under different growth scenarios

The assumption on the underlying rate of economic growth in the EU is obviously key for assessing ETS reform options. The path of economic growth in the baseline scenario affects the demand for

[16] Our measure for changes in welfare is the Hicksian Equivalent Variation expressed as percentage of national income in the BAU. It excludes welfare effects of changes in emissions. For the EU as a whole, welfare changes of individual Member States are weighed according to national income.

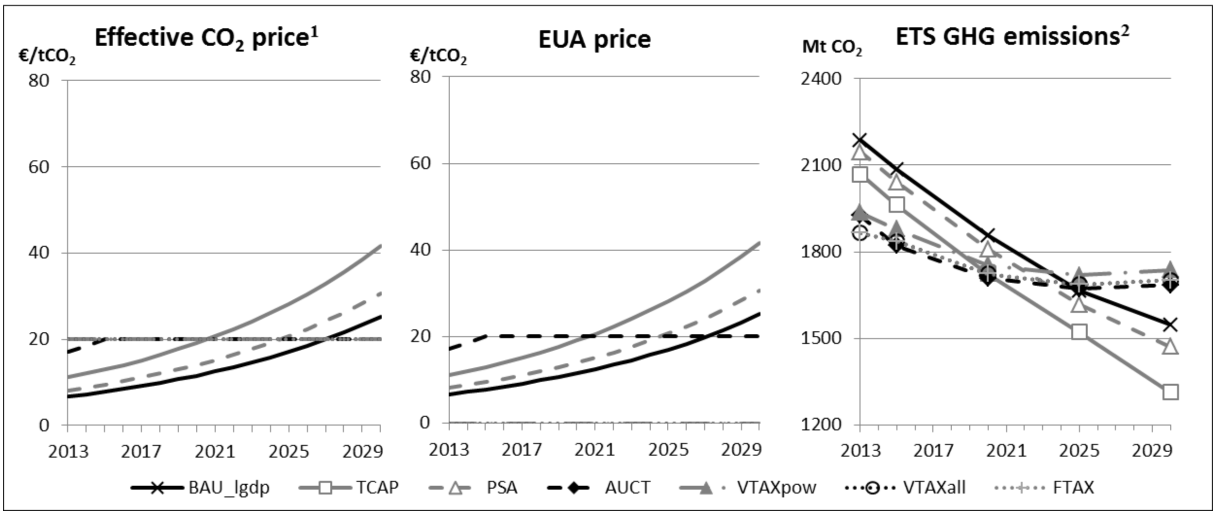

Figure 6. Effects on emission prices and ETS greenhouse gas emissions under a scenario of low economic growth in the EU (1.3% instead of 1.8%).

[1] For *VTAXpow* the effective CO_2 price applies to the power sector only; other ETS sectors only face EUA price.

[2] Emissions include emissions from EFTA countries included in the ETS; emissions from international aviation are not included. We report emissions for the years 2013, 2015, 2020, 2025 and 2030.

allowances in absence of reform and hence affects the price and emission paths resulting under the various reform options. Furthermore, the underlying growth path affects welfare directly through the opportunity costs of abatement, and hence EUA prices, and indirectly through the resulting emission paths (especially when cumulative emissions are affected).

The *BAU* scenario assumes GDP in the EU to increase annually by on average 1.8%. In the light of current European and global economic developments, this level may be somewhat optimistic. We assessed the consequences of a lower economic growth rate (i.e. 1.3%) in the EU for the impacts of each reform option. We applied our low growth scenario by adapting the macro total factor productivity (TFP) growth rate in the WorldScan model for the EU in such a way that a lower GDP growth rate is realised. We similarly assessed the impact of a higher economic growth rate (i.e. 2.3%).

Figure 6 shows the effects of the reform options in case of a low economic growth rate. First, note that in the absence of reform (*BAU_lgdp*), emissions prices are 40 percent lower than under the *BAU* path presented in Figures 3 and 4. Emissions are slightly reallocated over time with a small increase in early years and a small decrease in later years, with cumulative emissions unaffected: despite low growth, cumulative demand still equals cumulative supply.

Under the low economic growth scenario the 2013 emissions price is €6.70 as compared to €11.10 in the BAU scenario with 1.8% growth (scenario *BAU_lgdp*; solid line in Figure 6). In the absence of ETS reform it stays below €20 up to 2028.

Reform options *TCAP* and *PSA* increase the initial EUA and effective CO_2 price, relative to the case without reform to €11.10 and €8.20, respectively. Cumulative emissions are lowered compared to the case without policy in a way similar to that under the *BAU* growth scenario (8% under *TCAP* and 3% under *PSA*). The policy options that introduce a floor price at auctions or a tax support emissions prices much more strongly than *TCAP* and *PSA*: the tax options push the initial effective price to €20 while the auction reserve price leads to an initial EUA price of €17.10. Furthermore, they reduce cumulative emissions with 2% (*VTAXpow*) to 5% (*AUCT*). Since in a low growth scenario the opportunity costs of reducing emissions are lower than under a high growth scenario, this is a desirable feature of a hybrid cap-and-tax (or cap-and-reserve-price) system.

The effective carbon price initially almost triples under the tax and reserve price options, as compared to the case without ETS reform (under the tax options the EUA price drops to zero). The resulting effective emission price levels are much higher than under *PSA* and *TCAP*. Indeed, the auction reserve price as well as all three tax options make the EU ETS more robust to external shocks and are truly structural reforms: a new recession or the arrival of a new and cheap abatement technology cannot push effective CO_2 prices (far) below €20.[17] In addition, they may induce additional abatement when marginal abatement costs are low. *TCAP* and *PSA* both induce an increase in emission prices and a decrease in cumulative emissions. However, as we will see next, these options also decrease cumulative emissions in periods of high opportunity costs, contrary to the tax options and the auction reserve price.

We report the welfare effects of the reform options for the case of low economic growth in the EU in Figure 7. Tightening of the cap (*TCAP* and *PSA*) has slightly smaller welfare losses when economic growth is low, as the opportunity costs for additional abatement are lower. However, this is also the reason why for the other reform options welfare losses tend to be slightly larger with low economic growth: as noted above, the tax and reserve price options induce additional abatement (beyond the cap imposed by the EU) in when economic growth is low, precisely because opportunity costs are lower in times of low economic growth.

As was the case under *BAU* growth, largest welfare losses are incurred by newer Member States, notably Poland. Again, the largest dispersion in impacts occurs with the auction reserve price.

Figure 8 shows the impacts on prices and emissions for each policy option under high economic growth. Since under this scenario EUA prices are already above €20 from 2017 onwards in the absence of ETS reform, the effects of the variable taxes and the auction reserve price on prices and emission levels are much smaller as compared to the policy effects under *BAU* (Figures 3 and 4),

[17] It should be noted that for a variable tax in the power sector, this price only applies to this sector. Indeed, the EUA price and hence effective carbon price for all other ETS sectors becomes zero. Nevertheless, the cumulative emissions target is still met, albeit through emission reductions in the power sector only.

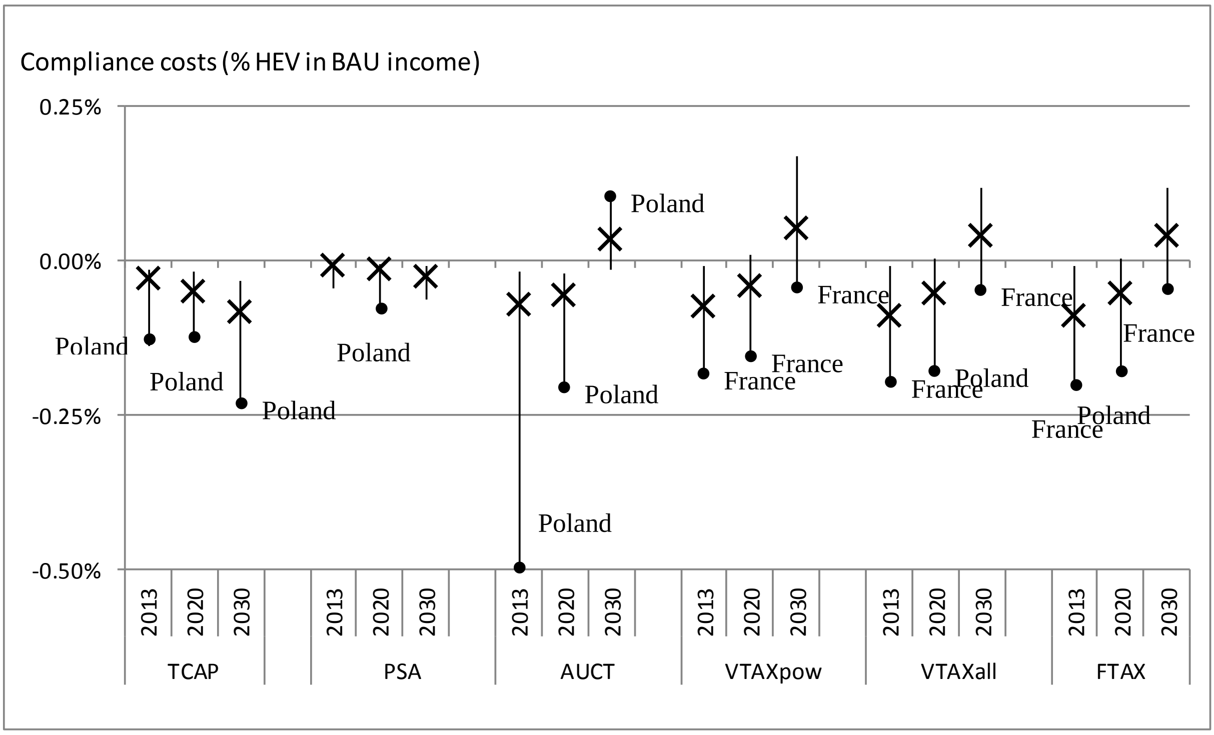

Figure 7. Compliance costs of policy options in 2013, 2020 and 2030 for EU27 as a whole (marked with cross) and for selected EU Member States; low growth scenario (Hicksian equivalent variation expressed as percentage of national income in BAU; range indicates variation between individual Member States).

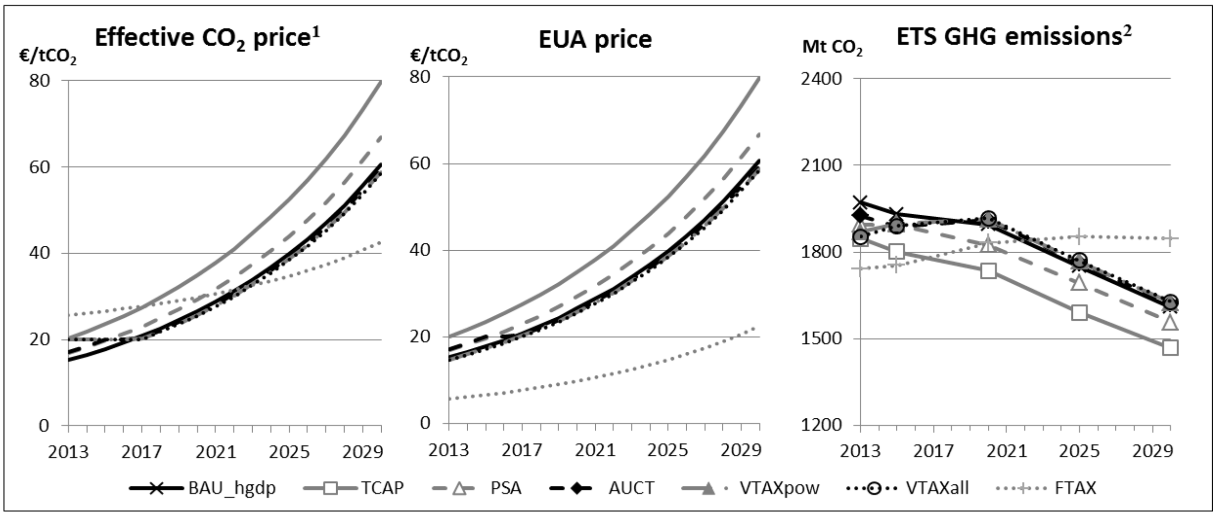

Figure 8. Effects on emission prices and ETS greenhouse gas emissions under a scenario of high economic growth in the EU (2.3% instead of 1.8%).

[1] For *VTAXpow* the effective CO_2 price applies to the power sector only; other ETS sectors only face EUA price.

[2] Emissions include emissions from EFTA countries included in the ETS; emissions from international aviation are not included. We report emissions for the years 2013, 2015, 2020, 2025 and 2030.

which is obviously a desirable feature. Indeed, if economic growth were even higher, the EUA price would be above €20 for all years, and the variable taxes and auction reserve price would not affect prices or emissions. The fixed tax would still induce an initially higher effective carbon price, and in later years a lower one, as compared to the other options, resulting in a flatter emissions path (right panel of Figure 8).

None of the tax and reserve price options affect cumulative emissions. Quantity options *TCAP* and *PSA* on the other hand, still reduce cumulative emissions by 8% and 3% respectively, even though under a high growth scenario the opportunity costs of emission reductions are higher.

5.2 Impact of the reform options under higher/lower tax and reserve price levels

Figures 9 and 10 show the results for a higher (€25) and lower (€15) level of the CO_2 tax and auction reserve price, respectively. Results are relative to the *BAU* scenario with 1.8% GDP growth and hence should be compared to the results in Figures 3 (*AUCT)* and 4 (*VTAXpow*, *VTAXall* and *FTAX*).

Figure 9 shows that the higher tax and reserve price cause the effective carbon price to be quite constant over time. The underlying cause is the fall in EUA price, as the €25 tax/reserve price crowds out the allowance price even further than with a €20 tax/price. Since the EUA price increases over time starting from a lower base as compared to a €20 tax/reserve price, the effective CO_2 price barely grows. The initial effective emissions price is higher than under the €20 rate, inducing strong early emission reductions (10-16% in 2013) and consequently strong increases in emissions relative to *BAU* in 2030. The initial price increase with the fixed CO_2 tax (from €11.10 to €26.10 in 2013) is sufficiently strong to even induce a decrease in cumulative emissions over the period 2013-2030: as the EUA price even falls below the CDM price, fewer CDM credits are used and more emission reductions take place within the EU, compared to all scenarios discussed previously. Whether this is socially optimal, depends on the true level of the social cost of carbon.[18]

With a €15 tax and reserve price (Figure 10), the (effective) emissions price is still supported as compared to the case without policy reform, albeit at lower levels. The time paths of emissions reflect those of the €20 cases, with cumulative emissions unaffected by the reform options. Obviously, the only reform option that still affects prices and emissions in case of a tax and reserve price below €11.10 (the 2013 *BAU* allowance price) is the fixed CO_2 tax: any positive fixed tax will induce a higher effective emissions price and lower emissions level in early years and a lower price and higher emission levels in later years.

[18] Nordhaus, W.D., 2014. Estimates of the Social Cost of Carbon: concepts and results from the DICE-2013R model and alternative approaches. Journal of the Association of Environmental and Resource Economists 1, 273-312. estimates the social cost of carbon for the year 2015 to be $18.60 per ton of CO_2 in 2005 US dollars, or $20.90 for the year 2013 in 2013 dollars. Using the 2013 exchange rate this is €15.70.

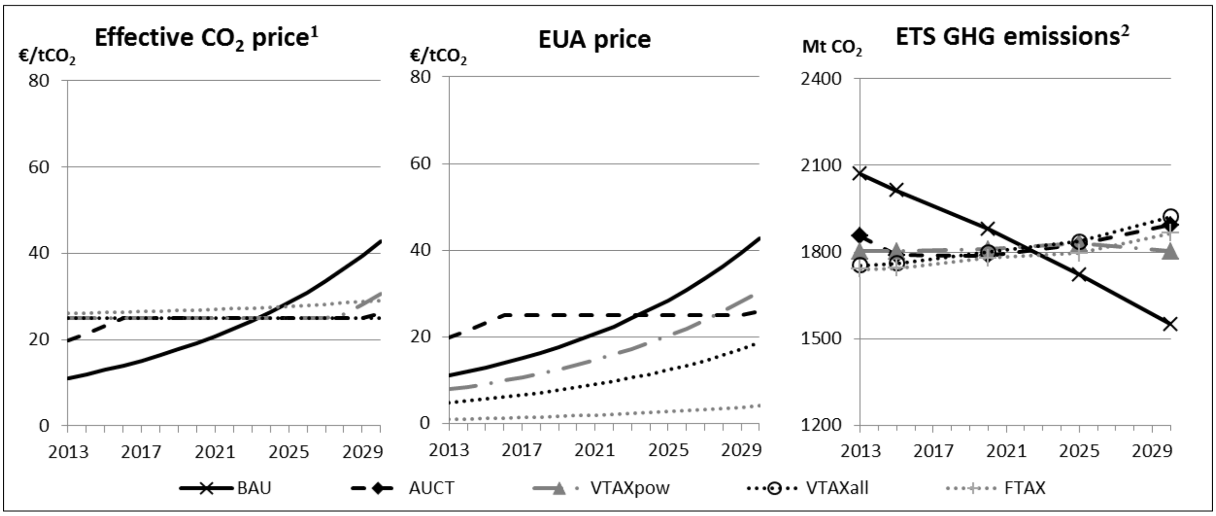

Figure 9. Effects on emission prices and ETS greenhouse gas emissions with a tax/auction reserve price of €25 instead of €20 (under a scenario of BAU economic growth, i.e. 1.8%).

[1] For *VTAXpow* the effective CO_2 price applies to the power sector only; other ETS sectors only face EUA price.

[2] Emissions include emissions from EFTA countries included in the ETS; emissions from international aviation are not included. We report emissions for the years 2013, 2015, 2020, 2025 and 2030.

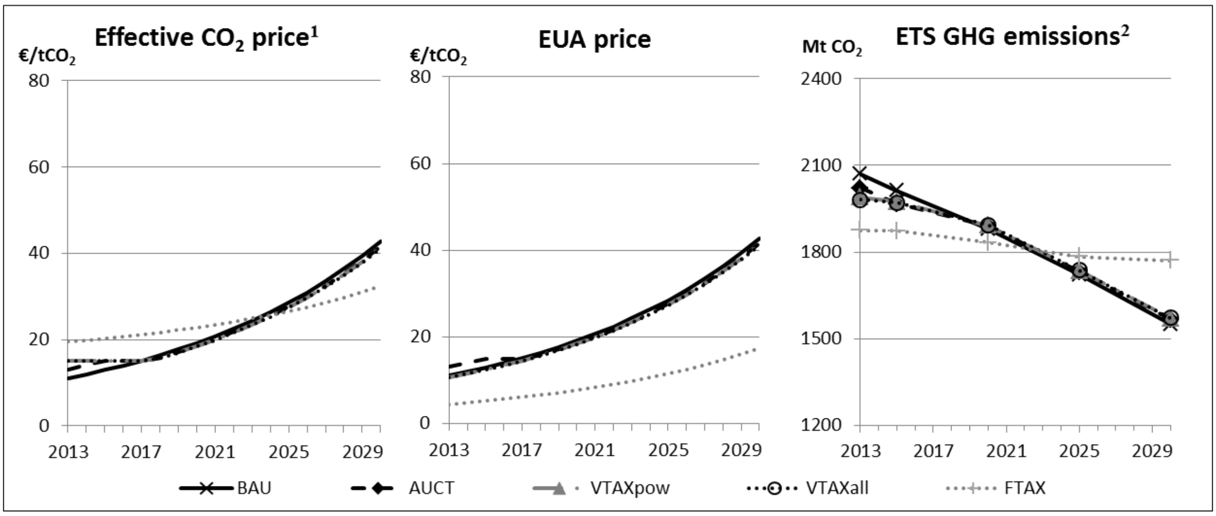

Figure 10. Effects on emission prices and ETS greenhouse gas emissions with a tax/auction reserve price of €15 instead of €20 (under a scenario of BAU economic growth, i.e. 1.8%).

[1] For *VTAXpow* the effective CO_2 price applies to the power sector only; other ETS sectors only face EUA price.

[2] Emissions include emissions from EFTA countries included in the ETS; emissions from international aviation are not included. We report emissions for the years 2013, 2015, 2020, 2025 and 2030.

6. Interaction with renewable energy policy

The EU has multiple targets and instruments aimed at reducing greenhouse gas emissions. Several studies have argued and shown that this affects the efficacy of individual instruments and leads to inefficiencies (e.g. Böhringer et al., 2009b). One of these targets is for the EU to generate 20% of its total final energy consumption from renewable sources in 2020. This target is included in all our scenarios as a restriction: we allow for subsidies on renewable energy such that the target is met in 2020. For subsequent years, we keep the subsidy rate constant at its 2020 level, which leads to a further increase in the share of renewable energy.

While with all policy options studied in this paper the 20% target is met, they all result in less renewable energy generation in absolute amounts. The reason for this decrease is that most abatement takes place in the energy sector, resulting in higher energy prices and a decrease in total final energy consumption. As a consequence, fewer Megawatt hours of renewable energy production are needed to reach the 20% target. The decrease in renewable energy production cumulative over the period 2013-2030 ranges from 1.2% in case of *PSA* to 4.6% in case of the fixed CO_2 tax. Moreover, in general, a higher effective carbon price reduces the subsidies required as the cost difference between fossil-fuel-based electricity and electricity from renewable energy sources decreases. As a result, fewer subsidies are needed to achieve the 20% target. The largest reduction in the net present value of the renewable energy subsidies granted in the EU27 is observed for the case of the increased linear reduction factor (95%). The smallest reduction is observed for *VTAXpow* (24%), in which case the lower EUA price for non-electricity ETS sectors hardly reduces total final energy consumption while at the same time fewer subsidies are needed because of the higher CO_2-price faced by the power sector.

To obtain more insights in the interaction between the ETS reform options and renewable energy policy, we created a new scenario. In January 2014 the EC proposed a new set of policy targets for the year 2030, including an EU-wide target for a share of 27% for renewable energy in total final energy consumption. Figure 11 presents the emissions prices and emissions levels for the case of a 27% renewable energy target for the year 2030.

In the absence of ETS reform, the 27% renewable energy target for 2030 induces a decrease in the initial EUA price from €11.10 to €9.70. The corresponding emissions path is slightly steeper with a small increase in initial emissions and slightly lower emissions in 2030 (cumulative emissions are the same).

In the presence of the 27% renewables target, all reform options induce an increase in the initial effective CO_2 price. As in the previous scenarios, this price increase is strongest for the fixed tax, followed by the variable taxes and auction reserve price. Since the renewables target affects the power sector, the two variable taxes now have slightly different effects on the EUA price and the effective CO_2 price in later years. The renewables target increases marginal abatement costs in the power sector.

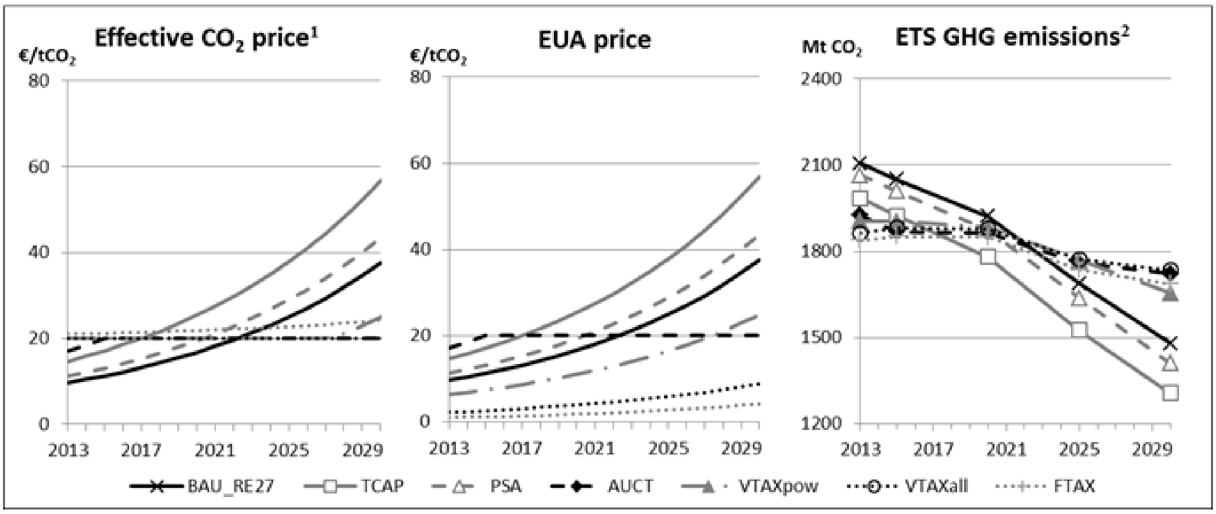

Figure 11. 27% renewable energy target for 2030.

[1] For *VTAXpow* the effective CO_2 price applies to the power sector only; other ETS sectors only face EUA price.

[2] Emissions include emissions from EFTA countries included in the ETS; emissions from international aviation are not included. We report emissions for the years 2013, 2015, 2020, 2025 and 2030.

As a consequence, a variable tax in the power sector leads to a smaller fall in the EUA price than a variable tax for all ETS sectors. The effective CO_2 price for *VTAXpow* is constant and equal to €20 up to 2028 and grows afterwards, whereas with a *VTAXall* the effective price equals €20 for all years. Tightening the cap through a higher linear reduction factor (*TCAP*) or permanent set aside (*PSA*) has smaller effects on the price.

We conclude that the auction reserve price and CO_2 taxes successfully support effective CO2 prices, even in the presence of overlapping regulation in the form of a renewable energy target.

7. Summary and conclusions

We have studied several options for policy makers to prevent the price for greenhouse gas (GHG) emissions in the European Union Emission Trading System (EU ETS) from falling (too) low. For this purpose, we employed a recursive dynamic general equilibrium model, WorldScan, that is capable of providing year on year insights into economic and environmental developments and of coping with detailed Member State-level data. It allows for banking but not borrowing of emission allowances, forward-looking behaviour on the allowance market, and explicitly takes into account the annual numbers of allowances allocated for free and auctioned.

We have studied four options for structural ETS reform aimed at preventing the effective carbon price to fall too low, and two ad hoc fixes. The ad hoc fixes effectively tighten the cap, which obviously increases allowance prices, but at the expense of higher welfare losses (excluding environmental benefits) as compared to the other options. In addition, these options do nothing to support carbon prices in case of future negative demand shocks, e.g. from a recession or the arrival of a new and cheap abatement technology.

Our structural reform options extend the quantity instrument that is the ETS with an auction reserve price (thereby staying within the scope of the ETS) or with a price component through the introduction of a tax on CO_2 emissions from use of fossil fuels. These options ensure a minimum price for emissions and provide automatic support for emission prices even in times of low demand for allowances. That is, they do not require ex post policy adjustments (such as cancelling of allowances) if a minimum price level is an (implicit) policy target. The tax options introduce a wedge between the effective CO_2 price and the EUA price.

The first structural reform option we studied was an auction reserve price of €20, where allowances that are not sold due to the reserve price are made available for auction in the next year. While this option supports the EUA price in early years, it results in below-baseline EUA prices at the end of the time horizon (2030). Interestingly, the auction reserve price causes large differences in welfare losses between EU countries, much more than the other price-based options.

Next, we looked at fixed and variable taxes on CO_2 emissions from fossil fuel use. The fixed CO_2 tax on fossil fuels for all ETS sectors was set at €20; sufficiently low to ensure that cumulative emissions are still determined by the cap of the ETS. This tax crowds out the price of EU allowances and initially induces a doubling of the effective carbon price compared to our business-as-usual scenario (BAU). The high EUA price in early years induces strong emission reductions while allowing emission increases relative to BAU in later years. In our sensitivity analysis we find that a sufficiently high tax induces an increase in cumulative EU emission reductions as it induces an EUA price that drops below the price for CDM credits. This, in turn, causes domestic emission reductions to crowd out emission reductions abroad that qualify for ETS emission reductions. Whether this additional abatement is socially desirable depends on the Social Cost of Carbon.

Next, we studied two variable CO_2 taxes on fossil fuels, on top of the EUA price, that keeps the effective carbon price at a minimum of €20: one for all ETS sectors and the other only for the electricity sector. Both options lead to emission paths similar to that of the auction reserve price. If the tax is only imposed on the electricity sector, other ETS sectors face lower EUA prices than in BAU. With a minimum effective CO_2 price of €20 or lower, most abatement takes place in the energy sector and hence taxing only the energy sector or all ETS sectors has little effect on emissions, emission prices and welfare. The difference in EUA prices for both options becomes larger as the minimum effective price increases.

We conclude that introducing an auction reserve price or a fixed or variable tax on CO_2 emissions from fossil fuels to the ETS can structurally support carbon prices within the EU ETS, even in the presence of a renewable energy target. Other cap-and-trade systems in the world, such as the Regional

Greenhouse Gas Initiative in the North-eastern United States and the joint cap-and-trade program of California and Québec, have a minimum price as well, both as an auction reserve price. Moreover, price floors (and ceilings) for emission trading have a sound scientific basis. However, in the EU ETS an auction reserve price induces a wider dispersion of welfare losses across EU member states than the tax options, with larger losses for newer members which makes political implementation hard. Furthermore, it might not bring the initial EUA price to the level of the price floor as firms might first decide to trade and use banked allowances rather than purchasing allowances at auctions at the reserve price. The fixed carbon tax induces an initial effective emissions price that is at least as high as for the variable taxes – indeed, in all cases but for low economic growth it induces the highest initial effective price. In this sense, it 'over-performs' as a means to introduce a minimum price for CO_2 emissions. Still, since the underlying EUA price is lower than for other reform options, the effective price grows at the lowest rate, resulting in a relatively low effective price in 2030. The fixed tax merely re-allocates emissions over time, except when it is set at a very high level: then it induces additional domestic abatement as the EUA price falls below the CDM price.

Cost-effective environmental policy requires marginal abatement costs to be equal for all sectors. From that perspective, differentiating the CO_2 price for the power sector and other ETS sectors is a poor reform option. However, we found that this differentiation hardly affects abatement decisions for a minimum CO_2 price of up to €20. For higher prices the difference becomes more pronounced. Since ETS reform will especially be resisted by sectors prone to international competition (i.e. not the power sector), a variable tax for the power sector only may be a reasonable alternative to an ETS-wide variable tax from a political economy perspective, when the minimum price is not too high.

We therefore conclude that the variable CO_2 tax options are the reform option that provide the best opportunity to structurally reform the EU ETS and make it more robust for unforeseen events.

The extent to which minimum emissions prices contribute to long-term investments in low-emission technologies (an implicit goal of the European Commission) is an open question – the WorldScan model does not allow for forward-looking behaviour on the market for investments in clean technologies, nor stochasticity of economic growth or other parameters (e.g. Pizer, 2002, Philibert, 2009). As we have seen, the minimum prices only re-allocate emissions over time, unless the auction reserve price or tax is set at a sufficiently high level to induce additional abatement. Indeed, only in case the cumulative cap is tightened, firms know that more abatement will have to take place in the future. Still, as we have shown, tightening of the cap is by itself no panacea against low emission prices in a future recession. To achieve both goals, it appears that a combination of a price floor and a tighter cap is necessary.

In sections 4 and 5 we have seen that a variable tax for the energy sector induced a wedge between the effective CO_2 prices for this sector and the rest of the ETS sectors, which may lead to a reduction in abatement efforts in non-energy sectors. This mechanism plays a role for all three tax options in case of linkage of the EU ETS with other trading systems (e.g. RGGI or the California-Québec trading system; see Wood and Jotzo, 2011). In that case European firms have to pay an additional tax and achieve additional abatement, which is likely to be offset by the partners in the joint trading system. Indeed, this is likely to be happening with additional abatement efforts in the UK energy sector: as this sector requires fewer allowances, the EUA price falls and other firms buy them, leaving total emissions within EU ETS unaffected. With an auction reserve price this seems to be less of a problem. In case of an equilibrium price below the reserve price, fewer allowances will be auctioned in the jurisdiction with the reserve price, (temporarily) reducing total supply.

A disadvantage of the reserve price in a linked system is that if the jurisdiction with the reserve price fails to auction allowances, it will receive less income for its budget which could potentially be used to lower distorting taxes (Wood and Jotzo, 2011). With a variable tax as price floor, on the other hand, the government will receive income as long as the allowance price is lower than the minimum price, while with a fixed tax receipts are guaranteed for years to come. These considerations of design of a floor price in the EU ETS in the presence of potential linkage to other cap and trade systems open an interesting path for future research.

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Appendix A: WorldScan methodology and assumptions

A1. Description of the WorldScan model

WorldScan is a multi-region, multi-sector, recursively dynamic computable general equilibrium model with a global scope. A detailed description of the model is given in Lejour et al. (2006).

A1.1 The production function

The production technology is modelled as a nested structure of constant elasticities of substitution (CES) functions. The values of the substitution parameters reflect the substitution possibilities between inputs. Figure A1 illustrates the nesting structure.

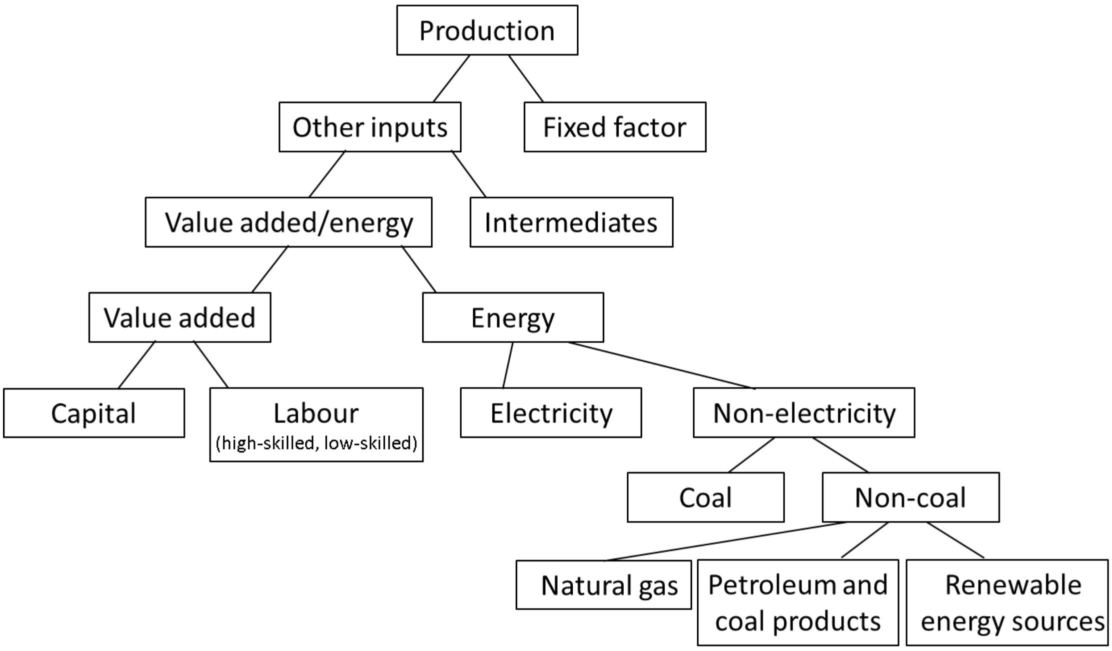

Figure A1: Production structure

The production function can be expressed by equation (A.1) for the nesting at the top level. At the top level, an aggregate of all variable inputs q_{TIR} is combined with a fixed factor q_{FIX} to generate output q_{TIN}. The nests at the lower levels are analogously defined.

$$\begin{aligned} q_{TIN} &= CES\left(q_{TIR}, q_{FIX}; \rho_{TIN}\right) \\ &= \left(\alpha_{TIR}^{1-\rho_{TIN}} q_{TIR}^{\rho_{TIN}} + \alpha_{FIX}^{1-\rho_{TIN}} q_{FIX}^{\rho_{TIN}}\right)^{\frac{1}{\rho_{TIN}}} \quad 0 < \rho_{TIN} < \infty \end{aligned} \qquad \text{(A.1)}$$

A1.2 Welfare analysis

In WorldScan, consumers save a fixed fraction of the level of their earned income. The income available for consumption is allocated to purchasing consumer goods and services. This is modeled as a Linear Expenditure System (LES) with consumers maximizing utility they derive from the consumption of goods and services, subject to a budget restriction and taking into account subsistence levels, i.e. the minimal quantity of consumption good *j* necessary to survive (see Lejour et al., 2006).

max $$U_c\left(c_{c,1}, \ldots, c_{c,n}\right) = B \prod_{j=1}^{n} \left(c_{c,j} - \gamma_{c,j}\right)^{\alpha_j}$$

subject to

Table A.1 Overview of regions, sectors, technologies and production inputs in WorldScan

Regions:	Germany, France, United Kingdom, Italy, Netherlands, Other EU15, Poland, Rest of EU27, EFTA countries, Russia, United States, Japan, Australia, Brazil, Middle East and North Africa, China, India, Other OECD, Rest of the World
Sectors[a)]:	Agriculture; Mining; Oil; Coal; Petroleum and coal products; Natural gas; **Power generation; Base metals; Chemical, rubber and plastic products; Paper, paper products and publishing; Non-metallic mineral products; Food processing, beverages and tobacco**; Other consumer goods; Capital goods and durables; Road and rail transport; Other transport; Other services
Non-energy inputs:	Low-skilled labour; High-skilled labour; Capital; Land; Natural resources
Power generation technologies:	Conventional fossil fuel-powered electricity; Fossil fuel-powered electricity with CCS; Nuclear energy; Wind and solar; Biomass; Hydropower
Non-electricity energy inputs:	Crude oil; Coal; Petroleum and coal products; Natural gas; Biomass; Ethanol; Biodiesel

[a)] ETS sectors are denoted in bold

$$\sum_{j=1}^{n} p_{c,j} c_{c,j} = Y_c$$

with $c_{c,j}$ the demand for consumption category j by consumer c, $p_{c,j}$ the corresponding price and Y_c the total consumption budget of consumer c. Parameter $\gamma_{c,j}$ reflects the minimal quantity of consumption good j necessary to survive.

Welfare analysis is based on the concept of (Hicksian) equivalent variation (EV), defined as the amount of money by which the income of a household in the baseline situation B should change to attain the utility level of an alternative situation V in which prices have changed, e.g. due to policy measures:

$$EV = e\left(p^B, U^V\right) - e\left(p^B, U^B\right)$$

with $e(p^B,U)$ the expenditure necessary to attain utility level U at baseline prices p^B (which is price vector $\left(p_1^B, \ldots, p_n^B\right)$ for baseline prices of consumption goods and services).

The change in welfare in year t is defined as the equivalent variation in year t as a percentage of national income in the reference scenario in year t.

A2. The ETS in WorldScan

Table A.1 gives an overview of the regions, sectors, inputs and energy technologies. In WorldScan, the following six sectors are covered by the EU ETS: Power generation; Base metals; Chemical, rubber, and plastic products; Non-metallic mineral products; Paper, paper products and publishing; and Food processing, beverages and tobacco. Auction revenues from the sale of EU ETS allowances

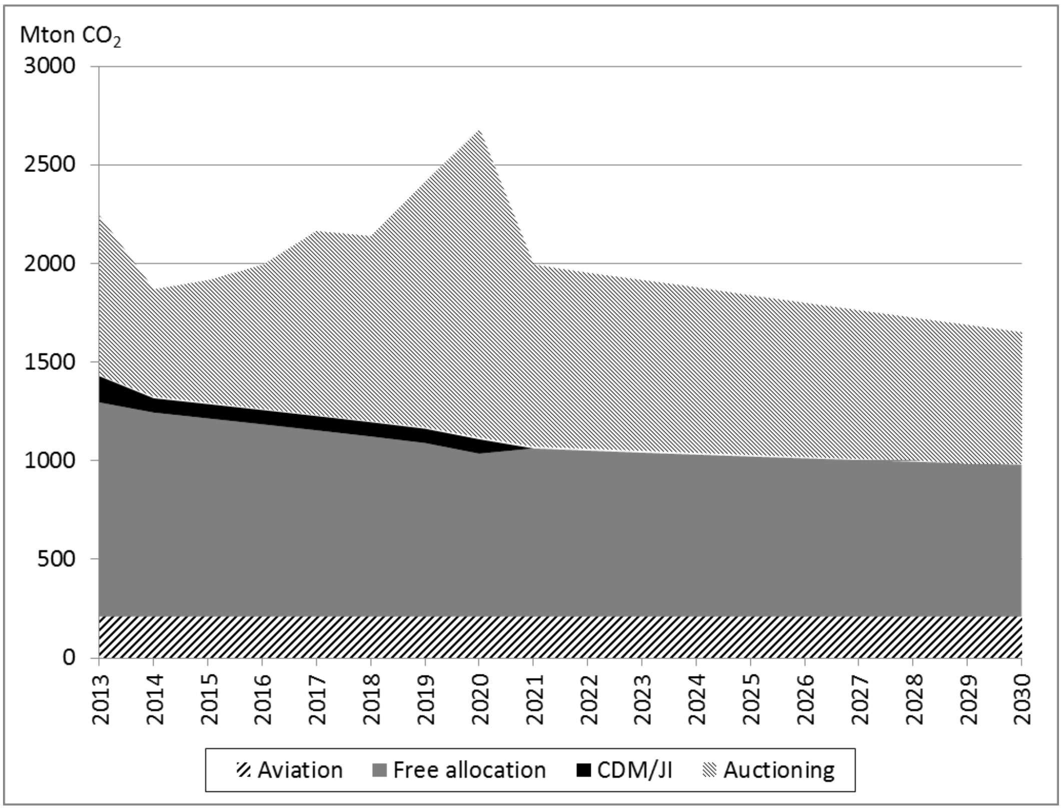

Figure B.1 Supply of EU ETS allowances and international credits in the Reference Scenario (Sources: EC (2012a), EEA (2012) and PBL calculations)

are redistributed in lump sum payments. To largely reflect the EU ETS allocation rules based on benchmarks of greenhouse gas emissions performance, the free allocation of allowances was based on the emission performance of each sector in 2010.

Appendix B: Reference Scenario

B1. Supply of allowances up to 2030

Figure B.1 summarises our assumptions about the supply of ETS allowances within and beyond the third trading period. Specific provisions in the current EU ETS Directive were taken into account, such as the timing of the auctioning and the distinction between auctioning and free allocation. We assumed the EU ETS will be extended beyond 2020 in line with current legislation, with full banking possibilities until 2030. Corresponding with the current linear reduction factor of 1.74%, the annual supply of EU allowances will decrease between 2013 and 2030 by 38 million allowances, annually. We also take into account the amendment to the EU ETS Auctioning Regulation postponing the auctioning of 900 million allowances until 2019-2020.[19] Under current ETS legislation, CO2 emissions from international aviation are included in the scope of the ETS. As international aviation is not well represented as an economic sector in the WorldScan model, the net demand for allowances related to international aviation was added exogenously to the ETS market. This demand was calculated assuming an annual emission growth of 2% between 2012 and 2030 (Kolkman et al., 2012). The potential use of credits from CDM projects is based on the assumption that the maximum use of credits from CDM and JI projects in the 2008–2020 period will be limited to 1.7 billion credits (EC, 2012a). In line with the current ETS framework, we assumed that the use of CDM/JI credits will not be allowed beyond 2020.

B2. Demand for allowances: Outlook for 2020 and 2030

The demand for emission allowances strongly depends on the underlying assumptions about economic development and energy demand and supply, not only in the EU but also in the rest of the world. Our Reference Scenario builds on assumptions about energy and macroeconomic developments in the Current Policies Scenario of the World Energy Outlook 2011 (WEO-2011, OECD/IEA, 2011).[20] Furthermore, we included the main current global climate policies. For the United States, Japan and other OECD countries, we assumed greenhouse gas emissions by 2020 to have been reduced according to the countries' unconditional Copenhagen pledges (UNFCCC, 2010). For the period beyond 2020, the relative reduction in emissions, compared to the WEO-2011 baseline scenario, was assumed to continue. In accordance with their Copenhagen pledges, China and India were assumed to have reduced their carbon intensity per unit of GDP, by 2020, by 40% and 20%, respectively, compared to 2005 levels. Beyond 2020, the carbon intensity was kept on a constant level. As the WEO-2011 does not present information on specific countries within the EU, we used the Baseline 2009 scenario that has been developed for the EC with the PRIMES model (PRIMES2009, Capros et al., 2010) to further disaggregate the developments for the EU.

In addition to the assumptions on EU ETS as described above, we also included other parts of the EU 2020 climate and energy policy package. First, for greenhouse gas emissions from non-ETS sectors (e.g. transport and households), we assumed the implementation of the national emission reduction targets of the Effort Sharing Decision for the 2013–2020 period. For the period beyond 2020 we assumed the relative reduction in non-ETS emissions, compared to the baseline, to remain at 2020 level. This implies a decrease in overall emissions of about 0.1%, annually. According to the Effort Sharing Decision, Member States will be allowed to meet their non-ETS targets in a flexible way; for instance, by transferring part of their annual emission allocation for any given year to other Member

[19] This amendment is referred to as 'back-loading' of auctions, according to Decision No. 1359/2013/EU of the European Parliament and of the Council of 17 December 2013 amending Directive 2003/87/EC clarifying provisions on the timing of auctions of greenhouse gas allowances.

States. Although this is not current practice, we assumed a cost-effective reduction to achieve the overall non-ETS emission target of the EU.

Second, the Renewable Energy Directive was included in the Reference Scenario by (i) a requirement of a 10% share of renewable energy in the transport sector by 2020, and (ii) introducing a uniform subsidy on renewable energy in power generation within all EU27 Member States to meet the EU target for renewable energy (a share of energy from renewable sources in gross final energy consumption of 20% by 2020) in a cost-efficient way. For the 2020–2030 period we assumed the share of renewable energy in the transport sector to further increase, in line with PRIMES2009. Subsidies on renewable energy in power generation were assumed to be kept constant, at the level needed by 2020 in order to achieve the 20% target, which will increase the share to 23% by 2030. This subsidy will be about 3% to 8% of production costs of renewable energy.

Finally, the Energy Efficiency Directive (EED), adopted in October 2012, was not taken into account. Although emissions from sectors covered by the ETS will be affected, both directly and indirectly (e.g. by changing demand for electricity), it is not yet clear what will be the specific policy measures implemented by Member States to promote energy efficiency improvements. Altmann et al. (2013) conclude that the impact of the EED on the EU ETS is likely to be limited because Member State policies directed at energy efficiency will mainly apply to non-ETS sectors, while in the impact assessment of the EED (EC, 2011a), the impact on CO2 prices in the EU ETS resulting from calculations by different models ranges from a limited decrease by 10% to 15% to a decrease down to EUR 0/tCO2.

Table B1 summarises the main characteristics of the Reference Scenario, including the average growth rates of GDP, energy use and emissions for the EU27 and for the entire global economy. These growth rates all result from our assumptions on macroeconomic development and energy use based on data from the WEO-2011 and PRIMES2009 *and* the assumptions on implementation of climate and renewables policies as described above. Table B1 also presents our assumptions on fossil-fuel prices, which were directly based on the WEO-2011.[21]

[20] Although the central scenario of the WEO-2011 is the New Policies Scenario, we used the Current Policies Scenario. This scenario assumes no new policies are added to those in place as of mid 2011. This scenario with the least policies implemented fits our purpose best to evaluate differences in design for different EU ETS options.

[21] The WEO-2011 takes into account the effect fuel prices from improved prospects for the commercial production of unconventional gas (shale gas). The WorldScan model assumes a globally uniform development in the price of distinct fuels; therefore, it was not possible to take into account regional differences in the development of fuel prices resulting from these developments. See also the discussion of this issue in Section 5.2.

Table B1. Main characteristics of the Reference Scenario

average annual growth (%)	2010–2020		2020–2030	
	World	EU27	World	EU27
GDP	3.4	2.0	2.7	1.8
Energy consumption	2.0	0.3	1.4	-0.1
- Coal	1.5	-4.4	1.6	-3.3
- Oil	1.2	-0.5	0.8	-0.6
- Natural gas	1.9	0.6	1.6	0.2
- Nuclear energy	2.5	-0.3	1.1	-0.2
- Renewable energy	4.7	5.6	2.5	1.9
Emissions				
- Greenhouse gas	1.4	-1.0	1.0	-1.0
- Greenhouse gas, ETS		-1.9		-2.1
Energy prices	2010	2020	2030	
- Oil (EUR 2010/barrel)	58.9	89.1	101.5	
- Coal (EUR 2010/tonne)	74.8	82.2	87.4	
- Natural gas (EUR 2010/million Btu)*	5.7	8.3	9.5	

* Gas prices are weighted averages expressed on a gross calorific-value basis (see OECD/IEA, 2011)