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The market (in-)stability reserve for EU carbon emission trading: Why it might fail and how to improve it

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ABSTRACT

The EU parliament has accepted a proposal of the EU commission on the backloading of EU emission allowances (EUA), where the auctioning of EUAs is postponed to future time periods. The EU commission has also proposed a market stability reserve (MSR), which is a quantity-based stabilisation policy that is aimed at controlling the volume of EUAs in circulation.

Using an agent-based electricity market simulation with endogenous investment and a CO_2 market (including banking), we analyse the backloading reform and the proposed MSR. We find backloading to only have a short-term impact of CO_2 prices; regardless, there is a significant risk of high CO_2 prices and volatility in the EU ETS.

Our simulations indicate that the triggers of the proposed MSR appear to be set too low for the hedging need of power producers, effectively leading to a stricter cap in its initial 10–15 years of operation. While the current proposal may be improved by choosing different triggers, a reserve that is based on volume triggers is likely to increase price volatility, contrary to its purpose. Additional problems are the two-year delay in the response time and the abruptness of the response function, combined with the difficulty of estimating future hedging behaviour.

1. Introduction

In recent years, the Europe Union's emission trading system (EU ETS) has experienced very low prices and a high level of price volatility. This has triggered a political discussion about stabilising the EU ETS and improving incentives for investing in CO_2 abatement. As a result of this discussion, the EU parliament accepted a proposal of the European Commission for “backloading” EU emission allowances (EUA), which means that a certain volume of EUAs is not auctioned until later (European Commission, 2012a).

A second stabilisation measure, proposed in Europe's climate strategy for 2020 to 2030, concerns a “market stability reserve” (MSR) (European Commission, 2012b). The MSR is a quantity-based policy instrument, based on the volume of EUAs in circulation. Both policy measures together mark a significant change of the EU ETS policy framework.

This paper investigates whether these two policies are able to stabilise prices (at a higher but still politically acceptable level) and to lower EUA price volatility. The long-term development of the power sector is characterised by strong path dependencies and non-linear relations. In addition, the actors are characterised by bounded rationality, especially with respect to investment decisions. The MSR itself also has a non-linear response function and works with a time delay. Therefore, we use the agent-based model EMLab-Generation (Richstein et al., 2014) to investigate the dynamic effects on investment of these policy changes. We extend this model to include backloading and the MSR.

In the next section, banking and hedging in the EU ETS are discussed because they play a key role in EUA price development. Next, the two policies are described and analysed (see Section 2). The model is introduced in Section 3, the results are presented in Section 4 and the conclusions are presented in Section 5.

2. Banking and the EU ETS reforms

In order to discuss the MSR and backloading, a short discourse into what motivates actors in the EU ETS to hold European Emission Allowances (EUAs) is necessary, since the MSR directly acts on the quantity of EUAs held. Afterwards we introduce the proposals of the European commission to stabilise EUA prices, and finally

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discuss the theoretic implications of the MSR and the backloading proposal.

2.1. The banking behaviour of power generators

We define banking as the holding of EUAs that exceed the amount needed for compliance in the current year. Two principal motivations are associated with banking EUAs: speculation based on future expectations of EUA prices and hedging future sales of products (most often power) that have greenhouse gas emissions as a side product or input cost (Schopp and Neuhoff, 2013).

Speculative banking in cap-and-trade schemes has a long history of treatment in academic literature, and is often simply referred to only as banking. On the one hand, this is because hedging was often ignored, thus making a distinction unnecessary, but also because it was often treated as a decision under abatement cost certainty, meaning that it was seen not as speculation but as a means of optimal planning. In general, a permit trading scheme will be efficient in achieving a cumulative emission target only if unlimited banking and borrowing is allowed and the social discount rate is used to make banking decisions (Rubin, 1996). This is also called inter-temporal efficiency because abatement takes place at those points in time that lead to a cost efficient achievement of the overall abatement target. For example, it may be efficient to postpone abatement, if considerable technological advancements that will lower future abatement costs are expected.[1] Leiby and Rubin (2001) discuss unlimited banking and borrowing[2] in permit trading for stock and flow pollutants under certainty (greenhouse gases are a stock pollutant due to their long-term effect). They find that if investors have a higher discount rate than a social planner,[3] companies will borrow more and bank less than is socially optimal. In other words, companies will postpone abatement further into the future than is socially optimal. To counter this effect, they suggest multiplying the volume of banked allowances with an interest rate to incentivise banking and promote socially optimal behaviour. Since Leiby and Rubin (2001) treat the problem as continuous and certain, they are possibly still under-estimating the effect of postponed abatement. Long-run infrastructures, that determine a large part of emissions, are discrete objects that have long-run effects and create path dependencies (see Section 3.1 for more details). Furthermore, heterogeneous actors make decisions under uncertainty. This could lead to further inefficiencies not captured by Leiby and Rubin (2001).

Newell et al. (2005) discuss the effect abatement cost shocks have on prices, meaning unanticipated changes in the costs of abatement to reach a given target, for example due to lower demand in a recession. Under unlimited banking and borrowing non-persistent shocks lead to quantity shocks, not price shocks, due to perfect inter-temporal arbitrage. For example in case of a negative shock, due to a recession, firms will foresee that abatement will still need to occur at the same costs level with a delay. Thus the CO_2 price stays at a similar level, but firms start to bank credits (or borrow less, depending on the original scenario). Thus, according to economic theory the current banking surplus is actually too small and not too big (at least under the assumption that the cap is set at the politically optimal level), since higher (inter-temporally efficient) current carbon prices would lead to an even bigger surplus. Newell et al. (2005) also discuss various options to stabilise prices under persistent abatement cost shocks by adjusting quantities based on fixed rules or discretionary action by the regulator.

Currently, hedging in the EU ETS is mainly driven by future power sales. This accounted for a majority of currently banked EUAs at the end of 2013 (Neuhoff et al., 2012; Tschach et al., 2014). Power companies sell their power on future markets to reduce volume and price risks (Doege et al., 2009). When doing so, they also cover the open positions for their production input, among them fuels and EUAs. According to Eurelectric (2009), power producers in Europe hedge between 10 and 20% of their output three years in advance, 30–50% two years in advance and 60–80% one year in advance on a cumulative basis. However, as acknowledged by the European Commission (2014) hedging behaviour may change over time: it depends on forward sales or contracts of companies, which in turn might vary with the risks and volatility faced in the markets in which the companies participate, the demand for forward sales, and whether they can pass on their EUA costs to their customers (which is why companies at risk of carbon leakage may be provided with free EUAs).

Neuhoff et al. (2012), based on a series of interviews with stakeholders, stipulate that there is a difference between the interest rates of speculative banking and hedging. The distinction between hedgers and speculators is an accepted insight in financial theory (Bailey, 2005). Furthermore, Schopp and Neuhoff (2013) point out that power producers might incorporate expectations about prices into their hedging strategies. They may, for example, increase the forward sales of carbon intensive production (e.g., coal) when they expect a tighter emission market (Schopp and Neuhoff, 2013). This could also be described as an attempt to lock in clean dark spreads,[4] that appear favourable to power producers. By changing their forward sales, they can hold more EUAs, while still having no open position (that is, they do not hold emission allowances for which they have not already sold the corresponding electricity. Deviating from this rule would be speculative banking and outside of the risk management criteria of many electricity companies). Thus, according to Schopp and Neuhoff (2013), up to the hedging horizon of 3–4 years and within the risk management criteria of power companies, banking takes place at a low discount rate (estimated to be between 0 and 10%). Banking volumes exceeding this hedging flexibility are discounted more heavily (rates exceeding 10–15%). This possibly explains the low prices in the EU ETS, since hedging flexibility, as determined by the risk management procedures of power producers, may well be exhausted.

2.2. Improving the ETS: backloading and the MSR

The so-called “backloading” is a rescheduling of part of the auctioning volumes of EUAs. As defined by the European Commission (2012a) and European Commission (2014b), for the years 2014, 2015, and 2016, 400, 300 and 200 million fewer EUAs respectively were intended to be auctioned than originally scheduled. These EUAs are auctioned at a later point in time, hence the term “backloading”: In 2019, an additional 300 million EUAs will be auctioned and in 2020 the auctioning schedule will be increased by 600 million EUAs.

The MSR is a quantity-based addition to the EU ETS active from the year 2021 on (European Commission, 2014a): The amount of EUAs that are auctioned is reduced if the upper threshold of 833 million EUAs in circulation is exceeded. In this case, with a two-year

[1] Assuming that there is no negative effect on technological advancement due to the postponement of installing abatement technologies.

[2] To the knowledge of the authors no existing carbon trading scheme allows borrowing. Possible reason are outlined by Fankhauser and Hepburn (2010), among them adverse selection.

[3] A social planner is a purely theoretical agent of welfare economics that optimises welfare results for all involved parties.

[4] The gross margin of coal power plants after obtaining fuels and emission allowances.

delay, 12% of the allowances in circulation at the time of triggering are placed into the reserve. If the EUAs in circulation fall short of the lower threshold of 400 million, 100 million EUAs are released with a two-year delay. Thus a soft target corridor for banking EUAs is introduced to the EU ETS. Additionally, 100 million EUAs are released from the reserve if the price of EUAs exceeds the average of the past two years by a factor of three.

These rules also can be described in terms of a response function, that is, the amount of EUAs injected or withdrawn from the primary EUA auctions based on the amount of banked EUAs. Central to this scheme is the speed (two years) and the shape of the response function. The current proposal is non-continuous and asymmetric, as seen in Fig. 1.

2.3. Uncertain effects of the proposed MSR

The concept of an allowance reserve for carbon trading schemes is not new to academic analysis. It was introduced by Murray et al. (2009), and compared to other instruments by Fankhauser and Hepburn (2010), Grüll and Taschini (2011) and Philibert (2009). So far, however, the term "allowance reserve" has, to the knowledge of the authors, been associated with an allowance reserve linked to price based rules. It can act as a simple price ceiling with a quantity limit (Murray et al., 2009), or via more elaborate rules, proposed by Taschini (2013) that avoid setting explicit price caps, by working with a price trend trigger, and a second quantity trigger that determines the size of the response. The European Commission (2014) assessed several policy intervention options and recommended the MSR based on pure quantity triggers. They acknowledged that there is considerable uncertainty regarding hedging behaviour of market participants, and did not perform an assessment of possible price effects, since "[m]odelling tools typically used by the Commission to assess the impact of certain targets, be it GHG target or specific energy targets, are better able to assess mid to longer term scarcities and price formation on the market, and are less well equipped to look at interaction of the drivers and uncertainties within short periods of time."

Several industry analysts, as well as academics have commented on the proposal. Acworth (2014) reviewed these initial (non-peer reviewed) comments, coming to the conclusion that most analysts welcome a change of the EU ETS, but are divided about whether the proposal of the European commission is the right way to achieve more supply side flexibility of emission allowances. Critics point

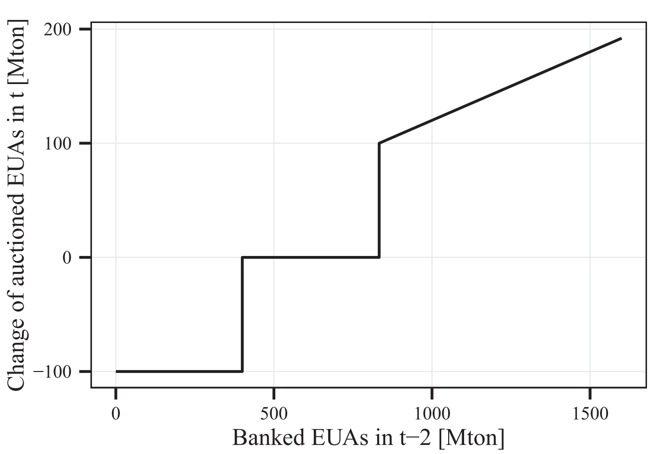

Fig. 1. Response curve of proposed MSR (not scaled to electricity sector of Central Western Europe and Great Britain).
Adapted from Tschach et al. (2014).

out that the MSR relies heavily on assumptions regarding the hedging behaviour of market participants and that the surplus might not be eroded quickly enough (Acworth, 2014). A simple rule based mechanism may not be able to accommodate for unforeseeable large disturbances (Trotignon et al., 2014; Grosjean et al.,2014). Finally, due to the two-year delay, the scheme suffers from a timeliness problem and might increase mid-term price volatility (Trotignon et al., 2014). In this paper, we focus on volatility effects, since the results of Trotignon et al. (2014) are only preliminary and not in-depth. Acworth (2014) concludes that detailed and balanced assessments of the MSR are lacking. In the following we discuss the MSR theoretically.

2.4. The effect of the MSR on price volatility

The economic rationale behind a MSR is inter-temporal efficiency (Tschach et al., 2014). As discussed in Section 2.1, prices do not correspond to the long-term efficient price signal needed for decarbonisation, since market participants have a higher discount rate than a social planner and will in general bank less than is socially optimal. This problem becomes more pronounced with macro-economic disturbances to an emission-trading scheme, since they momentarily reduce scarcity of EUAs.

The ideal stability reserve (whether price or quantity triggered) would thus immediately withdraw and inject the difference between the banking induced by a socially optimal price and the actual surplus held by private market participants. Based on the idea that banking still occurs (albeit too little due to a higher discount rate), a quantity based MSR should thus amplify long-term banking movements. Two aspects complicate that task in practice. First, EUAs are not only held in response to long-term future expectations but also for medium-term hedging. The baseline from which banked EUAs should be measured is thus the amount necessary for hedging. This amount is not easy to unambiguously determine (see Section 2.1), as medium-term expectations driven through adjustment of hedged power sales might lead to opposite movements in banked EUAs from long-term speculative banking. Second, since the intention of market participants when buying EUAs are not directly observable, the number of EUAs in circulation is the earliest available at the end of each year (when the verified emissions used to calculate the EUAs in circulation are reported). As a result, there necessarily is a delay of greater than one year in the response function of any quantity based MSR, which can possibly have counter-intuitive effects.

Table 1 shows for four different situations how the relative scarcity or excess of EUAs over time triggers the response of a MSR (assuming that the changes in banking are large enough to elicit a response). In the long-term structural excess situation, prices are low, since speculative investors are needed to stabilise the CO_2 price, who have higher discount rates that are significantly above discount rates of a social planner (Schopp and Neuhoff, 2013). This is current situation of the EU ETS. The MSR would withdraw EUAs in two years time. Since market participants can anticipate the withdrawal, the EUA price would be supported immediately. In a structural shortage, on the other hand, the banking stock is probably reduced, since non-compliance is heavily fined and EUAs would need to be handed in later. In this case, the MSR would inject EUAs to the market, thus reducing the scarcity. Presumably the MSR has been designed for these two situations.

However, not every change in the stock of banked EUAs necessarily is due to a structural excess or shortage. If market participants' expectations of the EUA price deviate from current future prices they will change their stock of banked EUAs. This change in stock can be based on pure speculation in EUAs, but also on a changed hedging strategy of producers, which has a time horizon of

Table 1
Banking & hedging scenarios.

Time horizon	Situation	Banking	Price w/o MSR	MSR
Long-term	Structural excess	↑	↓	Withdraws
Medium-term	Expected relative excess	↘	↘	Injects
Medium-term	Expected relative shortage	↗	↗	Withdraws
Long-term	Structural shortage	↘	↑	Injects

3–4 years (see Section 2.1). Due to the shorter time frames, as well as the hedging purpose, discounting rates are lower and the adjustment in EUAs in circulation is thus closer to the surplus induced by an optimal price. Because of the two-year delay, the response of a MSR can coincide with the expected event that led market participants to hold a higher stock in the first place. This dynamic could thus exacerbate already existing scarcity. It is thus important to include these dynamic effects in an analysis of the MSR.

3. Model description and assumptions

We first explain our choice of methodology. The following summarises the description provided in Richstein et al. (2014) and de Vries et al. (2013), in which the model EMLab-Generation was first introduced. The reader is kindly referred to Richstein et al. (2014) for a complete definition of the model. Except for explicitly mentioned differences, the model and scenario assumptions used here are identical. The contribution of the paper at hand is the addition of the MSR to the model. This model extension is presented in Section 3.5.

3.1. Choice of modelling methodology

The power sector and the EU ETS are characterised by several features that are difficult to model with traditional tools:

1. The price formation processes in power markets and decisions of agents are non-continuous and can be highly non-linear.
2. Power plants are discrete objects with different underlying technologies and long lifetimes.
3. Markets delegate decision-making in terms of infrastructure investment and operation to private, heterogeneous agents (compared to an optimising central entity).

The long life-times of power plants cause the system to be path dependent; investments made now influence costs, emissions and investments in power plants for decades to come. As a consequence, the power sector cannot be assumed to be in a long-run equilibrium, let alone in a long-run optimum, since the external factors (fuel prices, demand levels, technological development) affecting the equilibrium are constantly changing (Olsina et al., 2006). The decarbonisation of the power sector is a process that will take at least several decades. As the emission rate now is much higher than it should be in the long run, the cumulative emissions over this period will have a large impact on the total long-run cumulative emissions. When evaluating the effect of climate policy on the power sector, the emissions over the next several decades should therefore be considered, rather than a possible end state which is still several decades away at least. Because the path dependency that is caused by investment decisions can be expected to have a significant impact on the emissions during the next decades and should be considered when analysing the long-run effects of climate policy.

Investment decisions are, at best, characterised by bounded rationality (as defined by Gigerenzer and Selten, 2002). Due to the complexity of the decision environment, deep uncertainties[5] and the limited processing capabilities of even large firms, investors rely on satisficing criteria, such as hurdle rates or scenario analysis (Groot et al., 2013). Investors make reasonable decisions with the resources they have. Examples are easy to find: Spain, the Netherlands and Germany have significant over capacities of combined cycle gas turbine (CCGT) power plants, partly due to errors in the forecasts of demand and EUA prices and underestimated impact of renewable energy policy.

While other methodologies exist to investigate the power sector, agent-based models (ABMs) are especially well suited for analysing this type of problem. In an agent-based model, according to Bonabeau (2002), "a system is modelled as a collection of autonomous decision-making entities called agents. Each agent individually assesses its situation and makes decisions on the basis of a set of rules". Computers are then used to execute the algorithmic description of the agents, which results in the emergent macro-behaviour of the system under investigation. Epstein (1999) argues for using an ABM when investigating a problem in which "[…] individual behaviour is nonlinear and can be characterised by thresholds, if-then rules, or nonlinear coupling". This corresponds to point 1 at the beginning of this section. ABM also is well suited to simulate out-of-equilibrium economics, the process of equilibrium formation, and the inclusion of historical path dependencies (Arthur, 2006); this corresponds to the challenge raised under point 2. Finally, according to Epstein (1999), ABMs exhibit characteristics that make them fit for problems characterised by bounded rationality and agent heterogeneity (point 3).

Several authors have applied ABMs to the long-run development of the electricity sector in recent years: To investigate issues such as market concentration (Botterud et al., 2007), CO_2 cap and trade systems and CO_2 taxes (Chappin, 2011; Chappin and Dijkema, 2009), renewable policy (Fagiani et al., 2013), the interaction of renewable policy with climate policy (Fagiani et al., 2014), as well as generation adequacy (Ringler et al., 2014). These observations also led to broader research project from the authors of this article investigating the long-term impacts of climate policies in the power sector, the creation of EMLab-Generation, and resulted in a first investigation of price caps in connected electricity markets (Richstein et al., 2014).

The policies of backloading and the MSR have additional characteristics that can be represented by agent-based modelling. The backloading policy is related to the challenge of path dependency: the research (and modelling) question is whether this variation over time influences the decarbonisation path. The time delay by which the proposed MSR responds to high or low volumes of banked carbon credits requires a dynamic analysis; ABM provides a natural way of doing so.

[5] For example regarding fuel, demand and technological development, as well as political uncertainty.

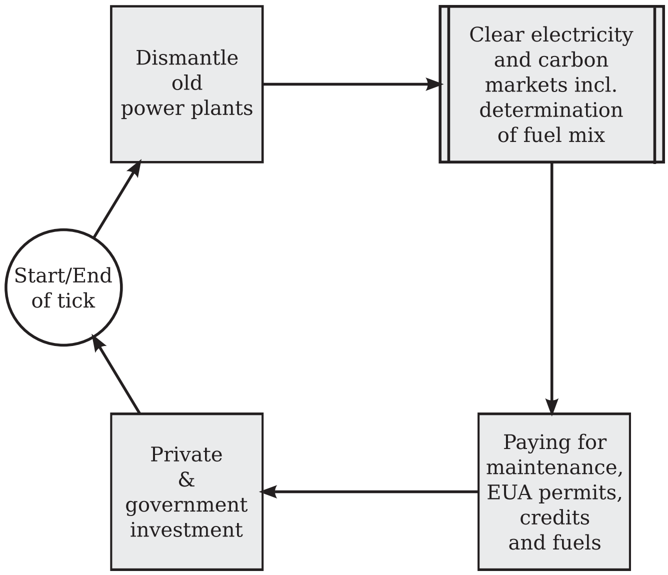

Fig. 2. Model flow diagram.

Table 2
Agents that are active in the investigated scenarios and their levels of complexity.

Agent names	Complexity
Energy Producer	High
TargetInvestor	Simple Rules
PowerPlantManufacturer	Accounting
PowerPlantMaintainer	Accounting
BigBank	Accounting
CommoditySupplier	Accounting
EnergyConsumer	Accounting
Government	Simple Rules
ElectricitySpotMarket	High
CommodityMarkets	Simple Rules

3.2. Model overview

EMLab-Generation is an open-source[6] agent-based model of two interconnected electricity markets with a common emission trading system modelled after the EU ETS, including the banking of EUAs by energy producers. The two electricity markets modelled in this paper are Central Western Europe (CWE, consisting of Belgium, France, Germany, Luxembourg and The Netherlands) and Great Britain (GB). Flows through an interconnector are determined by market splitting. The time step of the model is one year.

Several types of agents are modelled; their behaviour is described in terms of different roles (Chmieliauskas et al., 2012). The sequence of the main roles is depicted in Fig. 2. In Table 2, an overview of the agents in the model is provided, as well as a classification of the complexity of their roles. As the main agents in the model, the energy producers have a high level of complexity. They bid into the electricity markets, determine the fuel mix of their power plants and buy fuel, make investment decisions, pay for the various expenses, and maintain a bank balance. Fuel availability is unlimited; fuel prices are scenario variables. As a proxy for national, subsidy-driven investment in renewable energy, a subclass of energy producers with simpler investment behaviour was created; these ‘target investors’ invest only in renewable energy and the volume of their investment is exogenously determined.

In the CO_2 market, the volume of EUAs that is auctioned annually is also set exogenously according to the long-run abatement trajectory of the EU (see Appendix A for calculation of the emission cap, and incorporation of the backloading policy). The government adjusts this cap via the MSR mechanism, which is described in Section 3.5. The ElectricitySpotMarket clears the two electricity markets and the CO_2 market. The remaining agents in the model do not make active decisions, but simply serve as accounting entities who track the various types of expenses of the energy producers.

The development of the generation mix is an emergent result of the agents' investment decisions. These decisions are not necessarily optimal. Energy producers make long-term forecasts of fuels and CO_2 prices using regression analyses that serve as inputs to merit order forecasts for the two power markets. The agents have limited knowledge of the future, since in reality energy producers also face the challenge of forecasting and may make decisions that turn out to be sub-optimal ex-post (see also Section 3.1).

3.3. Power plant operation and spot-market bidding

Power plants are dispatched according to merit order. Single-fuel plants simply buy the fuel that they need. Energy companies that own multi-fuel power plants decide on their fuel mix by using a linear optimisation algorithm based on the previous year's CO_2 prices. As part of the combined clearing of the electricity and CO_2 markets, the fuel mix is updated so the fuel mix decisions are in equilibrium with the electricity market results.

The variable fuel cost $vc_{g,t}$ of power plant g in time step t is determined as the product of the volumes of the fuels (f) in fuel mix $s_{g,f,t}$ and the fuel prices $p_{f,t-1}$, divided by the fuel efficiency η_g of the power plant g:

$$vc_{g,t} = \sum_f \frac{p_{f,t-1} \cdot s_{g,f,t}}{\eta_g} \quad (1)$$

We assume that the energy producers add a 10% mark-up on the variable fuel costs to arrive at their spot-market bids. This approach is similar to Eager et al. (2012); modelling market power in more detail exceeds the scope of this paper.

3.4. Interlinked electricity and CO_2 markets

The electricity and CO_2 market clearing algorithm leads to optimal dispatch of the power plants, under the interconnection capacity constraint and an inter-temporal emission constraint (which takes expected emissions for a future year into account).

Because the model has a yearly time step, price variations are modelled by using a step-wise load-duration curve for each of the two electricity market zones. Each segment of the load-duration curve represents a number of hours with similar load levels. We use 20 segments (or load levels) in the model. Demand in each segment is assumed to be inelastic. This abstraction allows for shorter model run times, which make large Monte-Carlo simulations computationally feasible.

The two spot markets and the interconnector capacity allocation are cleared simultaneously through market splitting. In a first step, the bids of the power producers in the two markets are treated as belonging to a single market. The bids are sorted by price and the cheapest bids that are sufficient to meet demand are accepted. If the resulting interconnector flow is less than the interconnector capacity, the market is considered to be cleared. Otherwise, the interconnector is assumed to be congested. In this case, its capacity

[6] The source code used in this paper can be found in the online supplementary file or at https://github.com/EMLab/emlab-generation/tree/paper/euEtsMarketStabilityReserve, additional information at http://emlab.tudelft.nl/.

is added to the load of the exporting country and subtracted from the load of the importing country. The two zones are then cleared separately with the adjusted loads. The prices are determined by the marginal bids.

We describe here the basic CO_2 market, while the algorithms for the MSR are detailed in the following section. The algorithms for the CO_2 and electricity markets are closely connected. The CO_2 market adds an emission constraint to the current electricity market and a future expected electricity market. The ElectricitySpotMarketAgent nests the clearing of the electricity spot markets in an iterative algorithm which conducts a CO_2 price search under an emission constraint (Appendix A describes how the EU ETS cap is scaled). The degree to which the agents increase or decrease their volume of banked credits is determined centrally; the results of banking movements are prorated to the agents based on their emissions. In order to reflect the hedging and banking behaviour of electricity producers, the emission constraint should ensure that: a) the agents jointly try to hold enough EUAs for their hedging requirements, while b) that there is some flexibility for inter-temporal arbitrage.

In order to simulate inter-temporal arbitrage (as a result of which abatement occurs more efficiently over time), not only should the current time step be considered, but also the future. To limit computation time, we only take one reference year into account. Arbitrage takes place between the current year and three years later, which is a typical time horizon for the banking behaviour of electricity producers. The clearing emission constraint therefore includes the current year's emission cap $C_{CO_2,t}$ and the emission cap in three year's time $C_{CO_2,t+3}$.

The default volume of hedged EUAs is equivalent to 80% of expected emissions in the coming year, 50% of expected emissions in two years time and 20% in three years time. This is based on empirical data of the hedging needs of European power producers (Eurelectric, 2009; Neuhoff et al., 2012). This is represented in the model by a banking target $T_{B,t}$ from which the deviation $\Delta T_{B,t}$ to the current volume of banked emissions B_t is calculated ($\Delta T_{B,t} = B_t - T_{B,t}$). When the volume of banked EUAs that is held by the electricity producers is different from its target, the emission constraint is adjusted by $\Delta T_{B,t}/r$. The revision speed factor r determines how quickly the algorithm returns the banked volume of EUAs to the banking target. It is set to 3 in this simulation.

The current cap, the future emission cap, and the banking target are represented in a single clearing emission constraint, which then is compared to the emissions of the current year (E_t) and the expected emissions in three years time ($\widehat{E}_{t+3}$). The emissions are calculated by running the electricity market algorithm (described above) for the current year and for the future year (taking expected fuel prices, dismantlements and new builds into account), using the same CO_2 price $p_{t,CO2}$. (The CO_2 price is appreciated with a discount rate of 5% for the future year, $p_{t,CO2}{}^*(1 + i_B)^3$.) The CO_2 price that meets the constraint is found by the means of an iteration algorithm that is described by Equation (2), in which the sum of the CO_2 emissions in the current and the future years (the right-hand side of the equation) must equal the CO_2 caps in these years plus the difference in the volume of banked credits:

$$C_{CO_2,t} + C_{CO_2,t+3} + \Delta T_{B,t}/r = E_t(p_{t,CO2}) + \widehat{E}_{t+3}\left(p_{t,CO2}*(1+i_B)^3\right) \tag{2}$$

This procedure leads to banking behaviour as was described in Section 2.1: the agents try to achieve their hedging target over time. However, within a three-year period, the volume of banked EUAs can vary from the hedging target. This is due to the ability of the power producers to reduce emissions now rather than later, or vice versa, based on different abatement costs. If the emission cap cannot be met, a maximum market clearing price of 120 Euros/ton is assumed. At this price, power producers first consume their banked EUAs; if the cap is insufficient, additional EUAs are supplied according to the algorithm. The reason for limiting the CO_2 price in the model is that while more abatement at higher cost could occur in the model, in the long term there are abatement options with lower long-run marginal abatement costs. In addition, in practice other sectors are included in the CO_2 market, which provide more short-term abatement options, as a result of which prices should not be expected to rise to extreme heights. The 120 Euros/ton also represents an abatement cost level above which further CO_2 price increases have a diminishing short-term abatement effect in the model (see also Den Bergh and Delarue, 2015).

3.5. The market stability reserve (MSR)

The MSR is closely modelled after the actual, proposed design, as described in Section 2.2. Before the electricity and CO_2 markets are cleared, the MSR adjusts the EU ETS cap for the current year t based on the volume of EUA allowances that were banked two years ago. If the volume of banked EUAs is within a certain target corridor, the MSR does not change the cap; otherwise, the cap is adjusted. In our model, we scaled the target corridor linearly to the scope of the model (the electricity sectors of CWE and GB). If the banked allowances in $t-2$ are above the upper trigger, 12% of these allowances are deducted from the EU ETS cap in the current year. If the banked allowances in $t-2$ are below the lower trigger, the MSR releases a fixed volume of EUAs (See also Fig. 1.)

The model's CO_2 market algorithm should be adjusted in two ways. First, it should take into account the emergency price trigger that was described in Section 2.2. Second, the MSR should be factored into the current emission cap and its effects should be included in agent expectations for the future. This will influence the market equilibrium and therefore also the current CO_2 price.

If for more than six consecutive months the EUA price is above the average price of the past two years, the MSR emergency price trigger releases a fixed volume of EUAs. Since our model does not simulate events within one year, there are two possibilities for implementing this rule. One is that a high price in the current year triggers a release of credits in the following year. Alternatively, when the EUA price is above the trigger, the EUA price finding algorithm is rerun with the release of EUAs for the current year. If the released quantity is large enough to offset the shortage, this could cause the EUA price to return to its normal level. We implemented the second option because its effect is more direct; the potential avoidance of high prices is justified by the downward pressure on prices that would be caused by the expectation of an emergency release.

To implement the MSR, the emission-clearing cap must be adjusted. When active, the MSR changes the volume of auctioned EUAs, so Equation (2) should reflect this change for the current year as well as the expected change in the volume of auctioned EUAs in the future. The original cap $C_{CO_2,t}$ in the model is substituted by the sum of the original cap and the action of the MSR in t (MSR_t), which depends on the volume of banked EUAs two years ago (B_{t-2}). The expected action of the MSR in three years time ($\widehat{MSR}_{t+3}$) depends on the expected banked EUAs in the next year B_{t+1} (due to the two-year delay). B_{t+1} is linearly interpolated between the banked emissions of the current year B_t and the projected banked emissions B_{t+3} in three years time. Both B_t and B_{t+3} are intermediate results available during the iterative clearing of the CO_2 and electricity markets. Thus the emission-clearing cap from Section 3.4 is adjusted according to Equation (3) to take the action of the MSR into account:

$$C_{CO_2,t} + MSR_t(B_{t-2}) + C_{CO_2,t+3} + MSR_{t+3}\left(\widehat{B}_{t+1}\right) + \Delta T_{B,t}/r = E_t(p_{t,CO2}) + \widehat{E}_{t+3}\left(p_{t,CO2}*(1+i_B)^3\right) \quad (3)$$

3.6. Generation technologies, initial portfolio, fuel price and demand trends

We modelled fifteen power generation technologies, based on the World Energy Outlook 2011 New Policies Scenario (IEA, 2011) and additional assumptions (Richstein et al., 2014), including a strong assumption regarding intermittent renewables. Since the model does not work with hourly dispatch but with a load-duration curve, the contribution of the renewables to the different load segments is assumed to be fixed by static contribution ratios. These were determined based on empirical data from Germany (for more details, see Richstein et al., 2014).

The initial generation portfolios in the model are based on Eurelectric (2012) data, as well as on the average age structure of different generation technologies in the EU (from RWE, 2008). As we do not model market power, we assume the power plants to be distributed equally among four energy producers per zone.

We model electricity demand as well as lignite, biomass, and uranium prices as stochastic trends, using a triangular distribution to calculate the yearly price growth. Natural gas and hard coal prices are modelled as correlated stochastic Ornstein-Uhlenbeck processes (see Richstein et al. (2014) for more details). They are mean-reverting to the central fuel scenario of the UK Department of Energy and Climate Change (Department of Energy and Climate Change, 2012), which we extrapolated beyond 2035.

The step-wise load-duration function is calculated from hourly ENTSO-E data from 2010 for CWE and GB. We assume demand growth to be constant over all segments of the load-duration curve.

3.7. Investment in generation capacity

Investment in new power plants in the model is an iterative process in which energy producers sequentially decide whether or not to invest. One company's investment decision therefore influences the subsequent decisions of other companies. Investments take place until no company identifies further investment opportunities. The order in which companies invest is random and companies only invest their own zones (either CWE or GB). Equity (at an interest rate of 12%) is assumed to account for 30% of investment capital, while the remaining 70% is assumed to be debt (at an interest rate of 9%).

Generation companies base their investment decisions on a net present value (NPV) calculation for different power generation technologies, choosing the technology with the highest specific NPV per megawatt (and only if the NPV is positive). NPVs are calculated from bottom-up merit-order forecasts of the electricity spot market in the generators' own zones. The expected operational costs and revenues are calculated for a reference year (6–8 years ahead, varying among agents to create heterogeneity), taking into account expected age-based dismantlement as well as power plants that are under construction (including the ones announced in the current year). The agent estimates for fuel prices, CO_2 prices, and demand growth are based on a regression analysis of historical prices in the model. The number of years used for regression analysis varies between 4 and 6 for the different agents, leading to slightly heterogeneous investment decisions. The annual capital costs are the amortised loan costs. For a full description, please refer to Richstein et al. (2014).

The renewable target investors fulfil the renewable energy policy targets, which are an exogenous input of the model (see Richstein et al. (2014) for details), by bridging the gap between the government targets for installed renewable capacities and private investment in renewable technologies.

4. Results and discussion

This section is divided into three parts. In Section 4.1, we discuss the specific EU ETS reforms, backloading, and the MSR, as proposed by the EU commission. We do so by analysing CO_2 prices, emissions and banking behaviour. We also include a sensitivity analysis regarding the hedging assumption of energy producers, and the starting year of the stability reserve in this part. In the second part (Section 4.2), we analyse the alternative design choices for the MSR. In the third part (Section 4.3), we present a simplified model illustrating the volatility effect the MSR might have on EUA prices. Due to the stochastic input parameters and the long-term nature of the model, we expect a wide range of results. Therefore, the figures show uncertainty envelopes and, where necessary, a statistical analysis of the results is carried out.

4.1. The proposed EU ETS reforms

4.1.1. Scenario description

We analyse three policy scenarios: the original EU ETS ("PureETS" scenario), the EU ETS with backloading ("BL" scenario), and a scenario with both backloading and the introduction of the MSR in year 2021 of the simulation (the "MSR" scenario). We perform a Monte-Carlo simulation for each policy scenario to test performance under different possible futures. As described in Subsection 3.6, we stochastically generated 120 different fuel price and demand time series. In order to avoid random differences in inputs for individual policy runs, we used the same 120 time series inputs for each policy scenario. This also enabled make pairwise comparisons of individual runs with identical inputs for fuel prices and demand development in different scenarios. Since we only analyse the contribution of the electricity sector to the EU ETS emissions, we scale the emissions cap and the volume of the MSR down to the electricity sectors of CWE and UK. Backloading is implemented by changing the volume of auctioned EUAs (see Appendix A).

4.1.2. CO_2 prices, emissions and banking

Fig. 3 shows the development of EUA prices and banked volumes by the electricity companies in the model. In the PureETS scenario, price spikes occur in most runs for the years 2021–2026. Reasons are the low initial prices, which delay low-carbon investment, and the age-based dismantlement of nuclear power plants.[7] The price spikes in the model occur because the sector needs to make a switch from a situation with abundant EUAs to one of increasing scarcity. Over time, the investments in CO_2 reduction cause the EUA price to stabilise.

While backloading has a significant effect on CO_2 prices in the initial years of the simulation, it does not lessen the price volatility and price shocks. Up to year 2016, backloading increases CO_2 prices, while there is a downward pressure on prices in years 2017–2020 as the EUAs are returned to the market. This corresponds to earlier findings by Trotignon (2012, p.117ff), whose model sees an initial price increase, followed by a price collapse. In our model, backloading only has a minimal impact on prices from year 2021 on. The upward effect on prices in the early years is not sufficient to induce

[7] Our model probably overestimates the effect of nuclear dismantlement, since CWE (via France) has an unusually high share of nuclear.

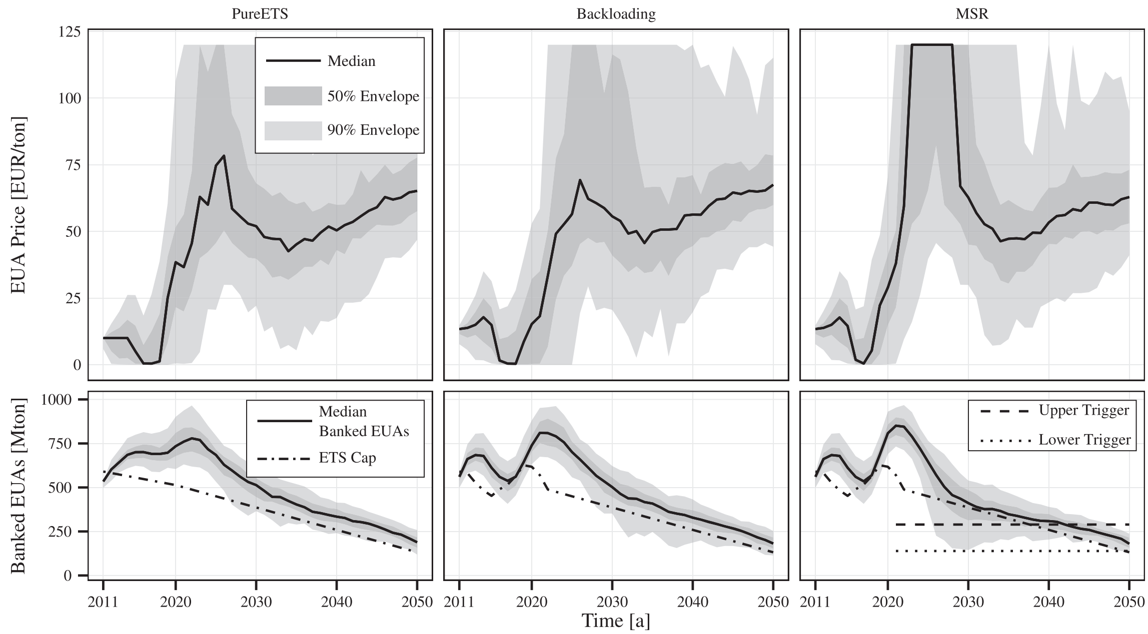

Fig. 3. EUA prices and banked EUAs. The upper and lower triggers are shown as dashed lines in the MSR scenario. For comparison, we added the scaled EU ETS cap.

enough low-carbon investments by energy producers to prevent a price peak around year 2026, which occurs both in the PureETS and the backloading cases of the simulation. A perfect market would completely price in the return of allowances to the market, leading to no price effect at all. In our model, we assume the cost-of-carry assumption to hold only for the three-year hedging time horizon of power producers. As a result, backloading does cause price increases and decreases.

If a MSR is introduced to the simulation in year 2021, the early years are identical to the BL scenario. Only from year 2018 on, when the future effect of the MSR is incorporated in the CO_2 price, the two EUA price paths diverge in the simulation results. While the MSR is intended to have a stabilising effect, within the context of this simulation, we observe that it increases EUA prices significantly in the years 2021–2031. It also increases the risk of shortage prices. The reason can be seen in the MSR panels of Fig. 3, which shows the simulated banking behaviour of power producers. The triggers of the proposed MSR are set far below the hedging demand of energy companies. As a result, the MSR is activated immediately, just when EUAs are already becoming scarce. The expectation of higher EUA prices in the future prompts companies to bank more credits than in the BL scenario, which exacerbates the shortage. Even without modelling speculative behaviour, the MSR appears to trigger a price ‘bubble’.

The very high EUA prices in the model would probably not materialise in real life; our model does not factor in the flexibility of the demand for EUAs in other sectors, electricity price demand elasticity, or any policy intervention that might occur if prices become too high. However, the results indicate a significant risk that MSR effects are contrary to policy goals, promoting instability rather than stability.

Until year 2040 of the simulation, the MSR constantly removes EUAs from the auctions in nearly all cases (Fig. 4). The emergency trigger created to release credits in case the EUA price triples within a short period of time only has a limited effect in the context of our simulation (and probably also in reality), for two reasons. First, high medium-term prices make it unlikely that credits are released from the MSR. To illustrate, a medium-term average price of 50/€ton sets

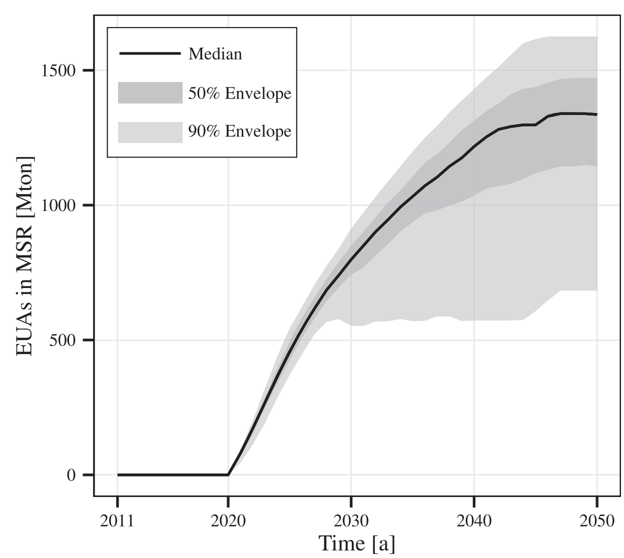

Fig. 4. MSR volume.

the price trigger to 150/€ton. Second, the regulation of the MSR is defined in such a way (European Commission, 2014b) that when the volume of banked EUAs is above the adding (lower) threshold of the MSR, the price trigger does not lead to a net release of credits from the MSR. It merely slows down the net addition of EUAs to the reserve, since the volume of EUAs in circulation is still above the target corridor. For instance, if prices have risen from 20/€ton to more than 60/€ton, but the volume of banked allowances is still higher than the upper MSR trigger (for instance because power companies expect the credit price to rise in the future), the emergency price trigger returns fewer credits to the market than were taken out due to the quantity trigger; the net effect remains a reduction of credits.

In our simulation, the effect of the MSR on emissions is quite clear. Since the MSR removes credits from the market and hardly

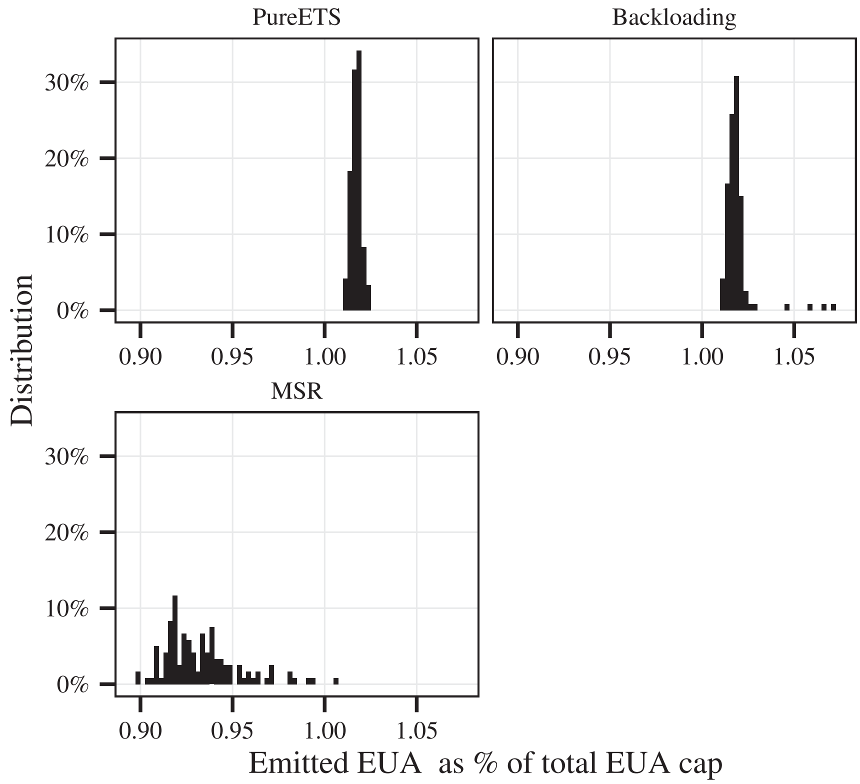

Fig. 5. Total CO_2 emissions.

releases any EUAs, the aggregate emissions over the entire simulation period are significantly below the emission cap by 5–10% (Fig. 5).[8]

4.1.3. Sensitivity analysis: CO_2 hedging assumptions

The hedging behaviour of power generators is a central model input and thus warrants a sensitivity analysis. As a first step, we analyse an additional scenario in which we assume that only electricity companies wish to hedge their risks by banking EUAs.[9] Since we do not explicitly model the other sectors, we investigate this by changing the relative levels of the trigger size. Whereas in the previous MSR scenario, the triggers were scaled to the size of the electricity sectors in CWE and the UK, as compared to the entire ETS, we now scale the triggers to the size of CWE and the UK electricity sectors as compared to the entire electricity sector in the EU ETS (see Appendix A). We limit our analysis to the differences in prices and hedging behaviour. Fig. 6 shows that even when it is assumed that there is no banking in other sectors, the triggers of the MSR still are set below the assumed hedging requirements of electricity producers. However, in 2031 for most of the simulation runs, the MSR ceases to remove EUAs from the auction. This relaxation of the cap leads to a slight depression in prices between 2030 and 2040.

Next, we analyse the effects of different hedging strategies of electricity producers on the MSR. In Table 3, the percentage of expected emissions that is hedged for the coming three years is detailed for the three sensitivity scenarios. The base scenario is the one used so far. The LowerBanking scenario is the lower estimation of hedging behaviour given by Eurelectric (2009). The TRBanking is a hypothetical hedging behaviour that would lead to a hedging target in 2021 in the range of the MSR triggers. We set the hedging behaviour for the static case, using the original emission cap, and scaling the hedging ratios down so that the emission cap multiplied with the banking ratios falls within the trigger levels.

We first analyse the effect of different hedging levels on prices in the scenarios without a MSR (PureETS and Backloading). Two periods can be distinguished in the simulation: one with low initial prices and a subsequent price peak (years 2011–2031), and another for the relatively stable period afterwards (Fig. 7). In the first period, the hedging strategies impact prices significantly. At lower hedging levels, the initial prices are lower, since power producers in the simulation need to bank less to reach their hedging target ratio (Fig. 8). This hedging ratio is above the starting volume of banked EUAs in the BaseBanking scenario, close to it in the LowerBanking scenario, and below it in the TRBranking scenario. In the context of the simulation, the price peak on the other hand is higher and has a longer duration with smaller banking ratios. This highlights the potential role that hedging might have played in keeping EUAs prices above zero in the recent years, as companies built up their hedging portfolio. In the period after year 2031, simulated price levels and volatility are relatively similar in the different hedging scenarios. This points out that barring external market disturbances, even a moderate hedging volume is sufficient to stabilise the ETS in the simulation.

In the presence of the MSR, there is no noticeable difference between the BaseBanking and LowerBanking scenarios. Only in the very low TRBanking scenario is the peak price period shortened, as the MSR takes out fewer EUAs due to the lower hedging

[8] It should be taken into account that the simulation starts with the agents having a certain volume of banked credits. Thus, the PureETS and BL case may have small excess emissions over the simulation period without breaching the cap.

[9] The demand for hedging in the other sectors in the EU ETS is debatable: even if they receive free allowances they should hedge to the degree that they can pass their opportunity costs on to their customers.

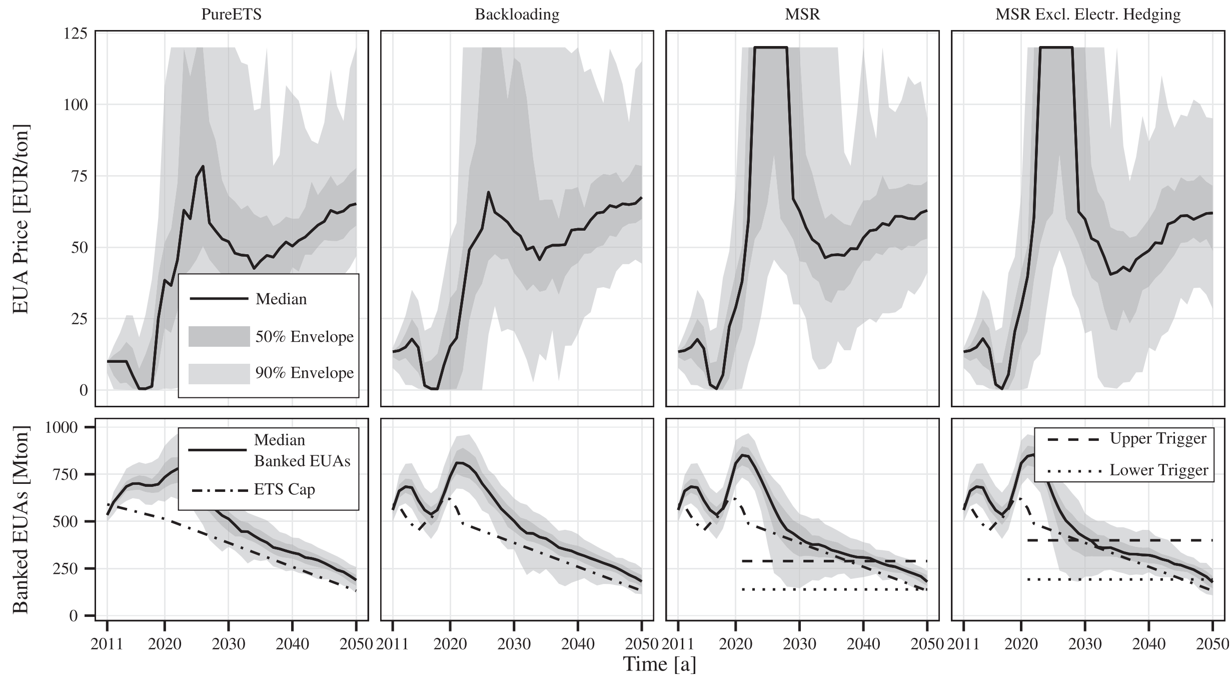

Fig. 6. Comparing the standard scenarios to a scenario where the electricity sector is the only sector with hedging requirements.

Table 3
Investigated banking/hedging ratios.

Banking assumption	1st year	2nd year	3rd year
BaseBanking	80%	50%	20%
LowerBanking	60%	30%	10%
TRBanking	26.7%	16.7%	6.7%

volume; simulated banking volumes thus reach the MSR target corridor much earlier. We do not, however, analyse the direct effects of lower hedging ratios on the electricity market. In accordance with the principle that there should be no open trading positions, we would expect future sales of electricity to also be lower.

4.1.4. Sensitivity analysis: introduction time for the MSR

Due to the backloading measure, a large volume of EUAs is returned to the market before the start of the third trading period and the tentative starting date of the MSR in 2021. This might lead to a collapse of EUA prices during this period. A possible countermeasure is to introduce the MSR at an earlier point in time. To investigate this sensitivity, we simulated the possible impact of introducing the MSR in year 2018.

As can be seen in Fig. 9, the earlier introduction date prevents a collapse of prices in the years 2016–2021. As a result of the more continuous EUA price and the earlier investment in low-carbon technologies, the mid-term peak is lower[10] and shorter. However, due to the shortage created by the MSR reserve in the years 2021–2031, the EUA price is in most cases still higher than in the backloading case. The lower part of the figure shows clearly that the early introduction shaves off part of the EUAs that are brought back to the market during backloading. This leads to less variation in the supplied EUAs and a more continuous banking path.

[10] An additional sensitivity analysis with a higher maximum EUA price showed the peak to be lower than in the base-case scenario.

4.2. Alternative designs of the MSR

In Section 4.1, we indicated that the parameters of the MSR are not set at the correct levels if our assumptions about hedging volumes are correct. In Section 2.4, we theorised that due to the time delay of the MSR and the potentially contrary effects of short-term hedging behaviour relative to long-term expectations, the introduction of the MSR might increase the volatility of EUA prices. In this section, we investigate the effects of alternative trigger levels on price volatility.

4.2.1. Scenario description

Since the MSR is intended as an integral part of the EU ETS for the foreseeable future, we investigated target corridors that decline in proportion to the cap, given that hedging volumes depend on emission levels. Since this declines with the cap, the trigger and response levels should decline proportionately.

The centres of the target corridors are determined by using three consecutive years of the EU ETS cap and multiplying them with the hedging ratios of the base-case scenario in Table 3. Around these target corridors, we perform a sensitivity analysis regarding the corridor width: ± 30%,± 20% and ± 10% of the target corridor's centre value, termed Cor30, Cor20 and Cor10 in the analysis. Next, we vary the response size of the MSR (i.e., how many EUAs are removed or injected to the market). Res10 corresponds in size to half the corridor width of Cor10 (based on a fixed percentage of total banked emission when directly at the upper trigger, and a yearly fixed amount when below the lower trigger). The same procedure was used to determine the response size of Res20 (with Cor20) and Res30 (with Res30). In the sensitivity analysis, we compare all combinations between Cor10, Cor20 and Cor30 and Res10, Res20 and Res30 (Fig. 10). The response curves for the first year of operation (year 2021) are depicted in Fig. 10. As the ETS cap declines, the response curves are scaled by the same ratio (also Fig. 12).

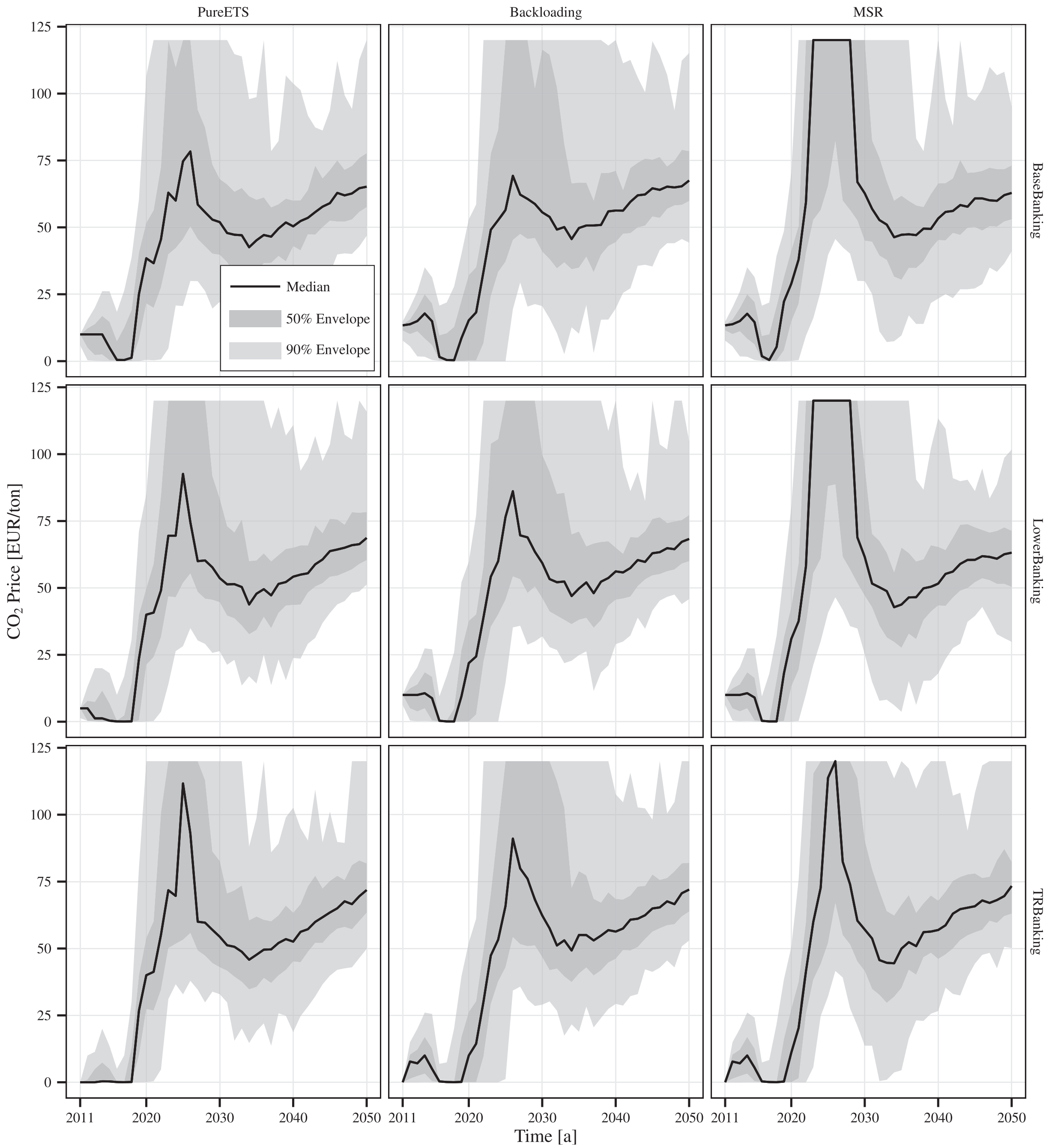

Fig. 7. EUA prices in different hedging scenarios.

4.2.2. *EUA prices and hedging*

Figs. 11 and 12 show the development of simulated EUA prices and banked EUAs over time. In general, the medium-term price peak increases with the narrowness of the banking corridor (Cor10 has a higher peak than Cor30) and with the strength of the response (Res30 has a higher peak than Res10). This is a direct result of the delay of the MSR and the general scarcity of credits around the year 2026: the more easily the MSR is triggered, and the larger the amount of removed EUAs, the more frequent and substantial is the EUA shortage in the simulation.

4.2.3. *EUA price volatility*

In order to check the hypothesis that a MSR might increase mid-term volatility, we compare its effect on the standard deviation (SD) of simulated EUA prices.[11] To make the results more robust, we only use EUA prices from year 2031 on (thus excluding the initial low price years and the price peak, which have an obvious increasing impact on SD) and perform a pairwise comparison between individual runs in the Backloading and MSR scenarios. Here, pairwise comparison means that the two individual runs that are compared have exactly the same exogenous input parameters (such as fuel-

[11] We use the standard deviation as a proxy for price volatility, since zero prices occur. Thus the standard measure of volatility, standard deviation of logarithmic returns, cannot not be applied.

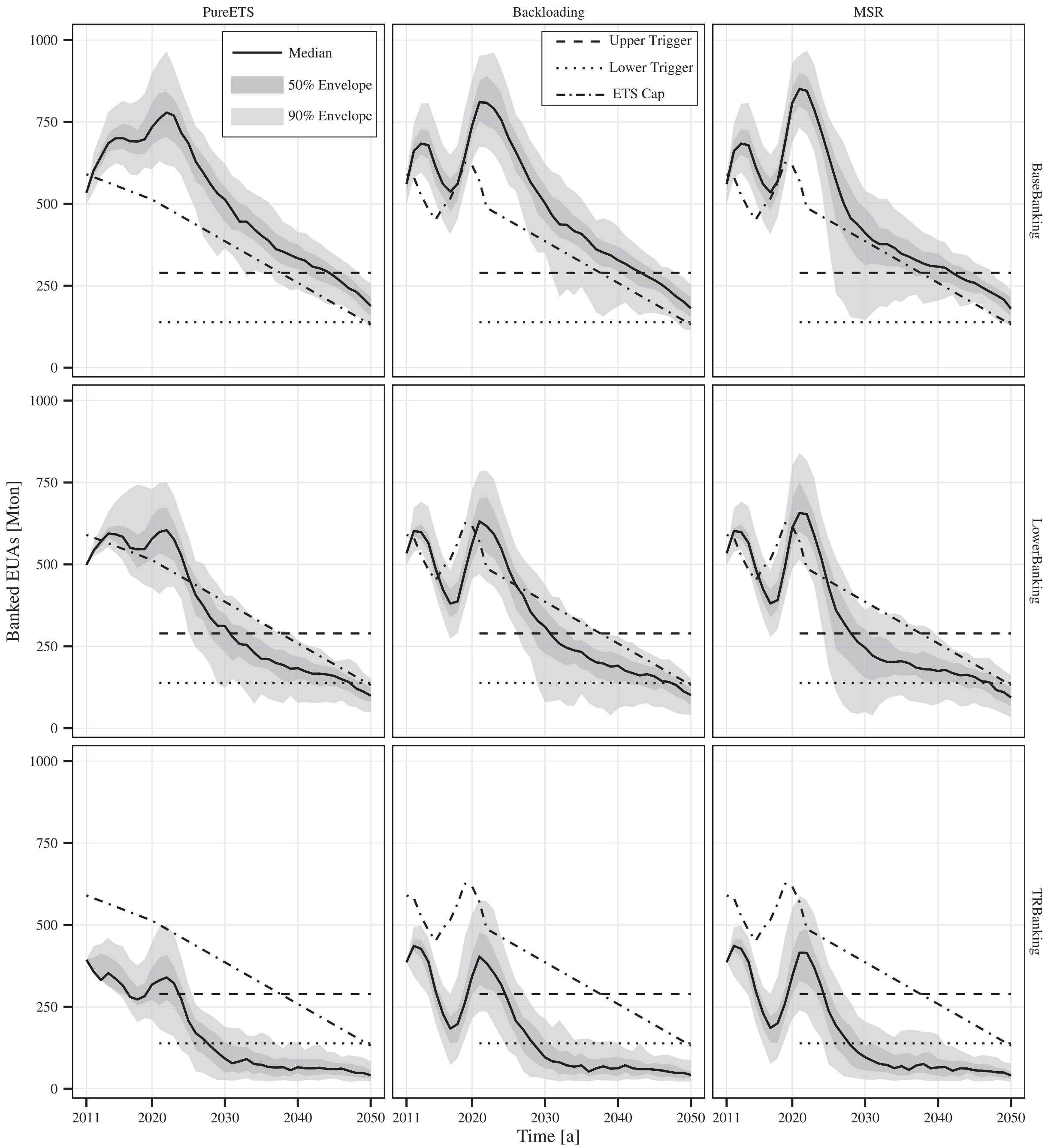

Fig. 8. Banked EUAs in different hedging scenarios.

price and demand-growth paths).

In general, the MSR was found to increase the standard deviation of EUA prices in the simulation. As evident in Fig. 13, the size of the increase varies significantly (with some individual runs showing a decrease in price SD). However, the increase of EUA price SD is statistically significant in all corridor scenarios, with a majority of runs having a larger SD than the Backloading scenario. Regarding the response size of the reserve and the corridor width, the results are mixed. While the median EUA price SD strictly increases with an increase in the response size of the reserve (Fig. 13 and Table 4), corridor width suggests no clear impact (Fig. 14).

4.3. Volatility analysis with simplified model

Since in the large-scale model, the effects of several factors (such as imperfect foresight and stochastic inputs) are superimposed, a simplified version of the model can be used to illustrate the reason behind the increased EUA price volatility. The simplified model has a linear load-duration curve, a static portfolio without investment of three types of power plants (coal, CCGT, and OCGT), and only a single exogenous change, namely the reduction of the emission cap in year 5 (dash-dotted line in lower-left panel). As can be seen in the standard case without the MSR (left side of the graph), agents reduce their emissions (dashed line in lower-left panel) three years ahead of

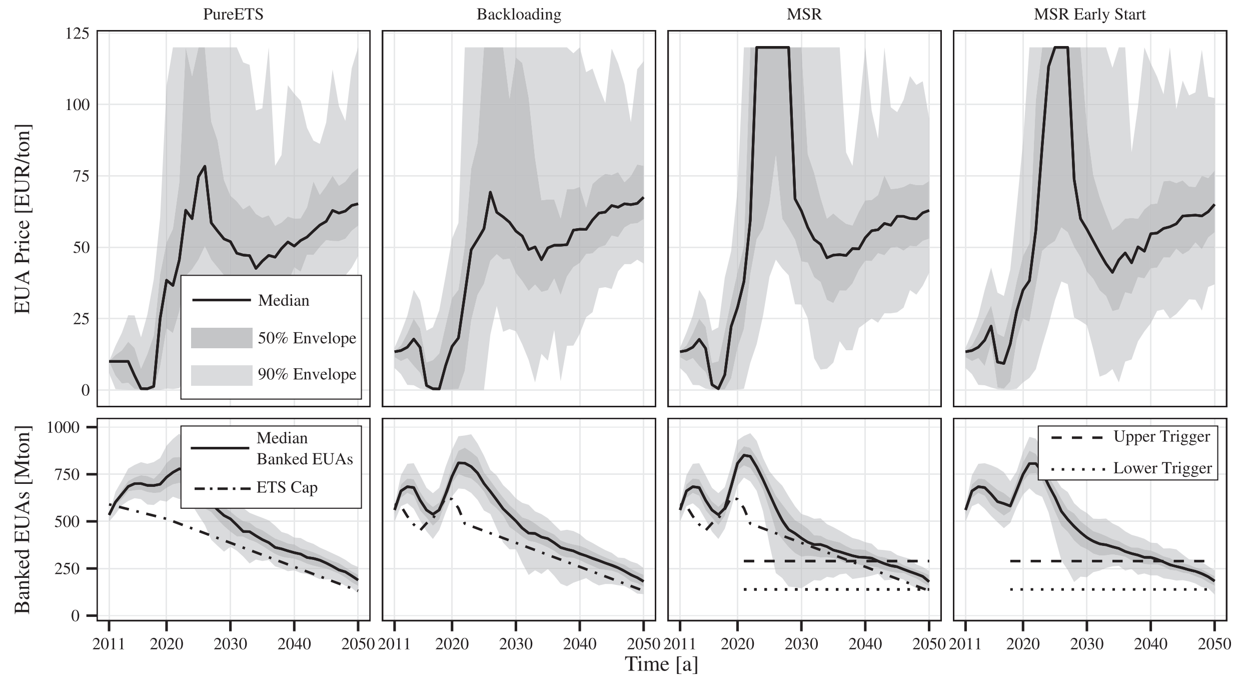

Fig. 9. Comparing the standard scenarios to a scenario with an earlier introduction of the MSR.

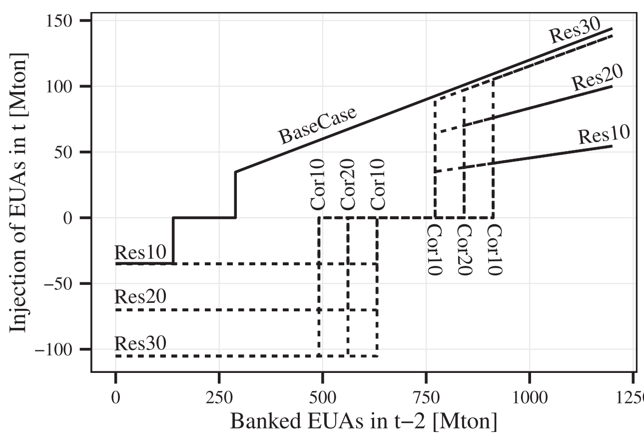

Fig. 10. Response curves of target corridors investigated in the sensitivity analysis for the first year of operation (year 2021). Later years are scaled down with the cap.

the reduction in the cap, which leads to an increase in banked EUAs. After the reduction of the cap agents reduce their banked EUAs to the new hedging-rate targer. As a result of this inter-temporal arbitrage, over time the EUA price gradually increases.[12]

In the right panel, the same situation is depicted with a MSR and a 30% corridor around the standard hedging rate of the power producers, which is reduced together with the cap. When triggered on the upper side, the MSR removes 16% of allowances from the market as occurring in years 5–8 (by reducing the emission cap in the affected years: dotted-dashed line lower-right panel). As can be seen, the MSR creates scarcity for a limited period of time, which increases prices. There also is a self-enforcing dynamic; the shortage induced by the MSR leads the agents to bank more EUAs, since they see approaching scarcity. This in turn leads to a larger MSR response (as explained theoretically in Section 2.4).

[12] The short decrease from year 2–3 is a model artefact.

Our model does not capture speculative banking. It could be argued that this would soften the price peak. However, we follow the argumentation of Schopp and Neuhoff (2013) and Neuhoff et al. (2012) in that hedging by power producers is limited to a time horizon up to 3–4 years, beyond which speculative investors have higher discount rates that limit their impact on market prices. One could also argue that agents would extend their banking horizon if their can clearly foresee this dynamic. This criticism has some justification, but to close their trading positions, they would also need to increase forward electricity sales by finding new buyers. Second, this dynamic would not be clearly visible given the noise of other market movements.

4.4. *Reflection on the assumptions*

Modelling is the art of capturing the essentials of a system with a simplified description. Reflecting on our assumptions and results, the model does not deliver precise market forecasts; we use it instead to investigate price and investment dynamics in the power sector, as well as implications for the EU ETS and potential reforms.

The model excludes a large part of the EU ETS; we only represent the electricity sectors of Great Britain and Central-Western Europe. Other economic sectors and countries are not modelled; nor do we model the price elasticity of demand. An example consequence is that the impact of the age-based dismantlement of nuclear power plants from 2020 to 2030 in France is exaggerated. We expect a larger market to dampen such effects.

Second, as previously mentioned, because the energy producers in the model are not able to forecast fuel prices, electricity prices, CO_2 prices, and demand growth perfectly, they are limited in their capability to make sound investment decisions. Power producers also are constrained with regard to credit banking for the next three years. As discussed in Section 2, we believe this to be a reasonable assumption. Nonetheless, if long-term speculative investors satisfied with lower interest rates were present in the market, they would likely dampen volatility effects induced by the time delay of the MSR.

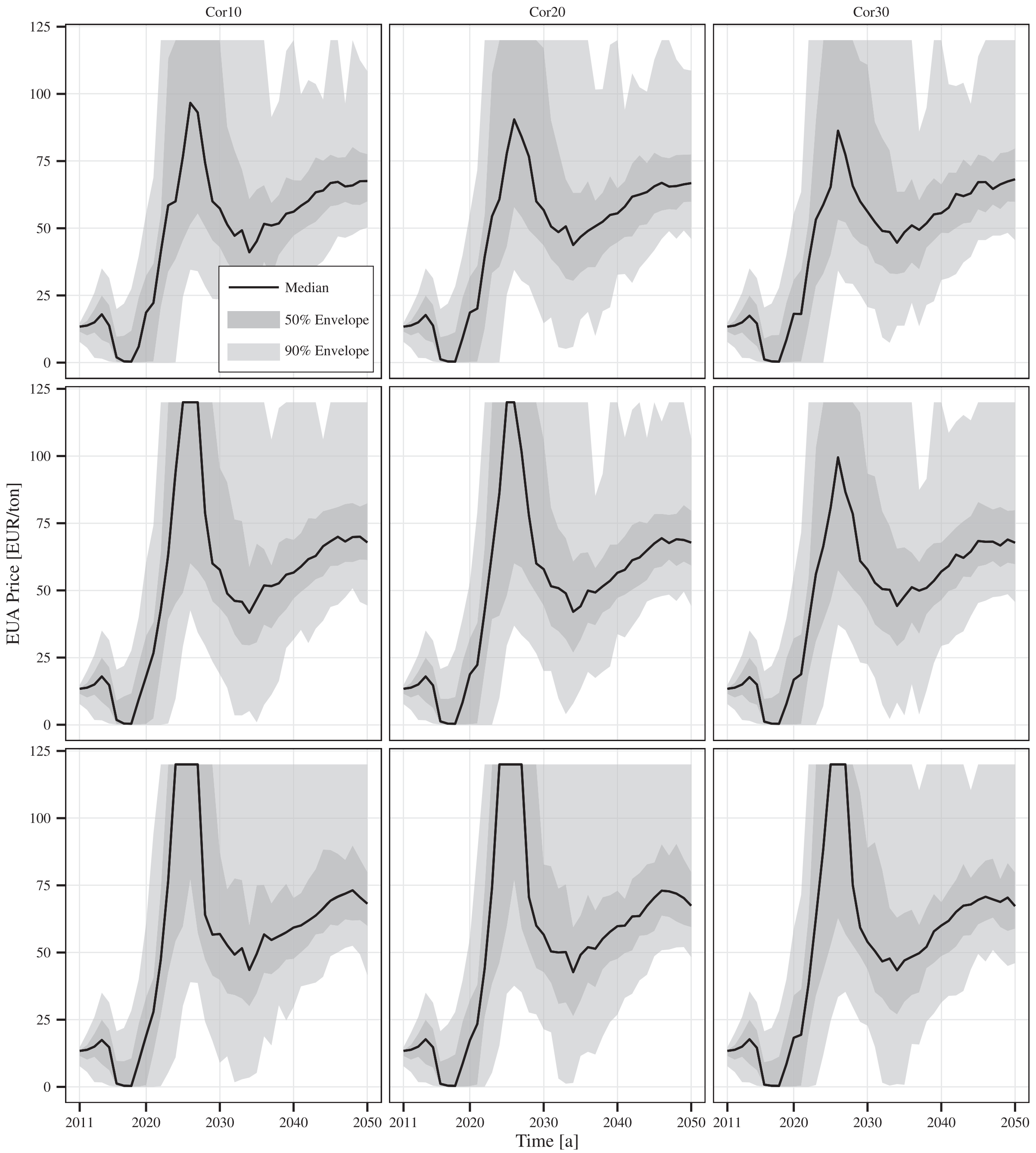

Fig. 11. EUA prices in alternative target corridor scenarios.

5. Conclusions and policy implications

We applied the agent-based model EMLab-Generation, which simulates investment in two interconnected electricity markets (based on Central-Western Europe and Great Britain), to investigate the possible effects of backloading and market stability[13] reforms on the dynamic properties of the EU Emission Trading Scheme. We also analysed alternative parameter settings for the MSR.

Backloading increases CO_2 prices in the short term but might lead to a price collapse when the permits are returned to the market at the end of the trading period. In the medium and long term, the effects of backloading are small. In the scenarios both with and without backloading there is a risk of CO_2 price shocks and consequently high costs to electricity consumers. Backloading mainly shifts prices and volatility to a later point in time. A key assumption in the analysis concerns the banking behaviour of EU ETS actors. We assumed that the dominant reason for power generators to bank CO_2 credits is to hedge their future electricity sales.

The proposed MSR appears to be at risk of destabilising the EU ETS. This could lead to an increase in CO_2 prices and price volatility. The primary culprit is the wrong parameterisation of the policy, which is designed to maintain a volume of CO_2 credits that is far lower than what we assume is the hedging need of companies.

[13] As proposed by the European commission.

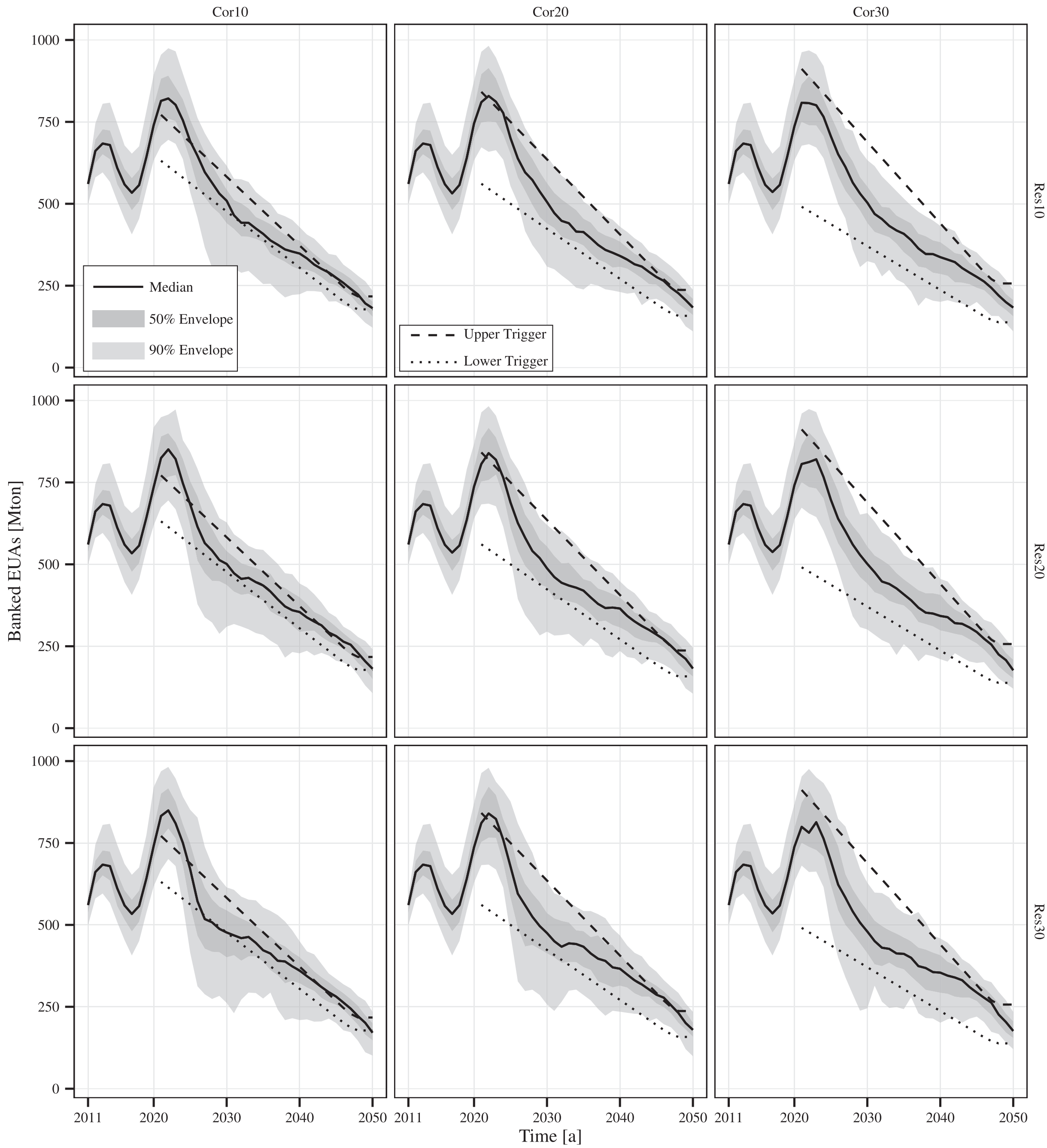

Fig. 12. Banked EUAs in alternative target corridor scenarios.

Effectively, the consequence is a one-time reduction in the volume of carbon emission allowances. If companies continue to hedge their future sales with banked credits, the volume of banked credits will always be so high that the reserve will not return credits to the market. Alternatively, power companies might not be able to hedge their future power sales.

Regardless of whether our estimation of hedging behaviour is correct, our results demonstrate the vulnerability of the MSR to inaccurate hedging assumptions. Given that it is difficult to forecast hedging behaviour, it is important to limit the sensitivity of the reserve's response function to inaccurate estimations of hedging demand. In the current design a large step change at specific trigger volumes for might increase price volatility in the market.

The commissions' proposal of the MSR contains the possibility of an emergency intervention in case of high prices. However, the rules for emergency intervention are designed in such a way that high prices might still occur without triggering a response. On the other hand, intervention could be triggered by a tripling of low prices (e.g. from 2 to 6 EUR/ton). Moreover, the price trigger may counteract the volume trigger in certain cases.

Finally, we find that even if the parameters of the MSR are adjusted to the hedging levels of power producers, the reserve might still increase EUA price volatility because the two-year delay might lead to a situation in which the stability reserve exacerbates a foreseeable shortage or excess of credits (which could be triggered by rational mid-term banking behaviour of agents).

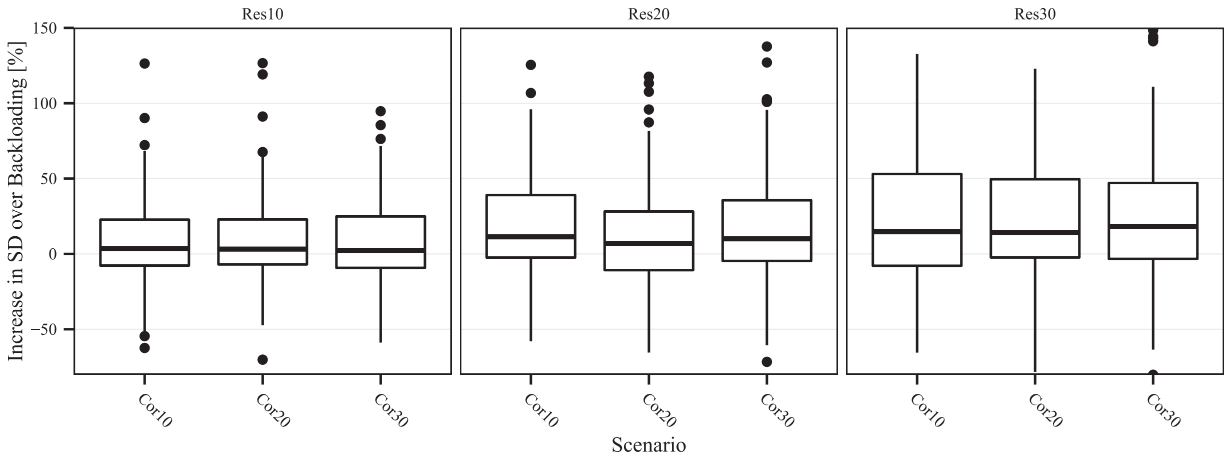

Fig. 13. Boxplot of the increases in standard deviation between the alternative target corridor scenario run and corresponding backloading run.

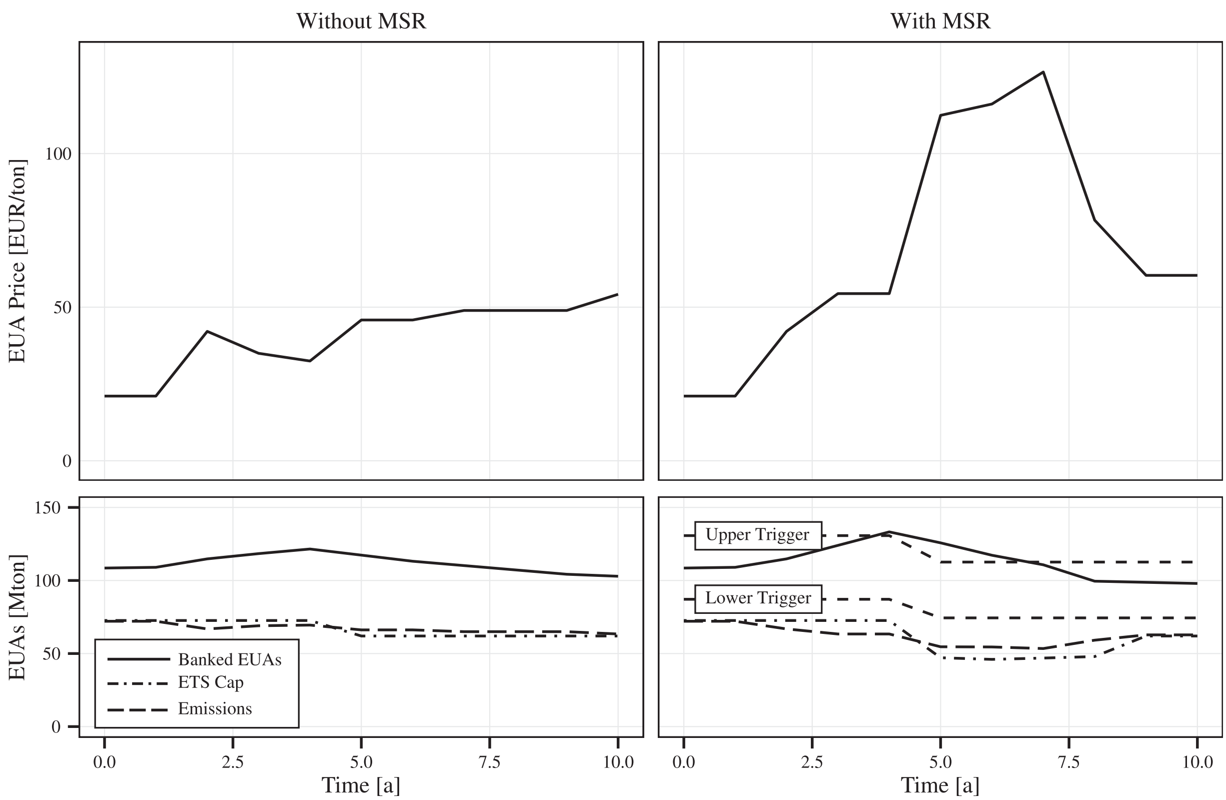

Fig. 14. Simplified model of an expected mid-term shortage with and without MSR.

Table 4
Increase of EUA price standard deviation in runs compared to Backloading.

Scenario/Quantile	25%	50%	75%
Cor30-Res30	−0.03	0.18	0.47
Cor30-Res20	−0.05	0.10	0.36
Cor30-Res10	−0.09	0.02	0.25
Cor20-Res30	−0.02	0.14	0.50
Cor20-Res20	−0.11	0.07	0.28
Cor20-Res10	−0.07	0.03	0.23
Cor10-Res30	−0.08	0.15	0.53
Cor10-Res20	−0.02	0.11	0.39
Cor10-Res10	−0.08	0.04	0.23

In order to improve the MSR, a continuous response curve should be adopted, as proposed by Tschach et al. (2014). However, this would not resolve the fundamental problem of the two-year delay. A constructive alternative would be the introduction of moderate EUA price floors and ceilings. Contrary to conventional wisdom, this would not jeopardise long-term abatement targets (Richstein et al., 2014). Another alternative is more discretionary adjustments of EUA supply, for example by a CO_2 central bank (de Perthuis and Trotignon, 2013). If these options are politically unfeasible, price-trend triggers as proposed by Taschini et al. (2014) might be better than the pure quantity triggers of the current proposal, since they do not suffer from delays and are not easily manipulated. Further investigation would be needed prior to implementing these proposals.

In order to prevent a price collapse when the backloaded credits are returned to the market at the end of the current trading period, the reserve should be introduced earlier in time. Alternatively, backloaded credits could be used as a starting stock of the reserve.

We recommend reconsideration of the MSR in the form originally proposed by the European Commission. Based on our model, it appears that the MSR might cause EUA price instability in the medium term. Our research shows that different trigger levels may improve the performance of the MSR, but determining optimal trigger levels will be difficult. Therefore we recommend adjusting the trigger levels when empirical data about banking and hedging become available. Further empirical research into the hedging and banking requirements of agents in the EU ETS is needed.

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Appendix A. Calculation of the emission cap and scaling of the MSR

The emissions cap is calibrated using the 20% reduction target for 2020 as compared to 2005 emissions (European Commission, 2010) and an 80% reduction target for 2050 as compared to 1990 emissions (European Commission, 2011). This also corresponds to the more recent goal of a 40% reduction by 2030 and the synonymous adoption of a 2.2% reduction factor from 2020 on (European Commission, 2012b).

We decided to use the data reported to the UNFCCC (European Environment Agency, 2012b) to first calculate the electricity specific emissions (using the emissions of the sector 1.A.1.A., "Public Electricity and Heat Production") in 2005 and 1990, to than deduct a linearly reducing emission cap. The reason for choosing the UNFCCC in contrast to the CITL data (European Environment Agency, 2012a) was twofold: the category in UNFCC ("Public Electricity and Heat Production") more closely matches the electricity sector than the sector 1. ("Combustion Installations") in CITL. Also, the UNFCC data reach back to 1990, as compared to 2005 for the CITL data.

For the scaling of the MSR, we used CITL data, since other sectors in UNFCCC are not included in the EU ETS. We compared emissions in CWE and GB in all sectors to the combustion installations in these regions, which resulted in a scaling factor of 34.7%. While this factor overestimates the emissions of the power sector, the overestimation clearly goes into the correct direction, since the power sector holds a majority of EUAs and this is the number relevant to scaling the MSR. In the sensitivity analysis discussed in Section 4.1.3, an alternative scaling factor of 72.41% is used, which is the percentage of combustion installation emissions in CWE and GB relative to all emissions of combustion installations in the EU ETS. This is a proxy for the assumption that only the electricity sector banks in the EU ETS.

Backloading is implemented by changing the volume of auctioned EUAs. We smooth the real-world changes in auctioning schedules out by spreading the backloading plans of single years over three years. The reason for doing this stems from how we model banking: since the CO_2 market clearing algorithm relies on the current year (t), and a future year (t+3), the simulation is sensitive to large changes in the auctioned volumes of EUAs in single years. In reality, actors' reactions would be more refined, resulting in a response more similar to smoothed backloading.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jup.2015.05.002.

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