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Major in Finance, Controlling, and Banking

# To what extent have the determinants of the $CO_2$ price changed over the last two years?

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## 1. Introduction

Even if it seems impossible now due to the COVID-19 pandemic or the war in Ukraine, more attention should be paid to global warming. Indeed, the last decade from 2011 to 2020 was the warmest ever recorded. Every 10 years, the global warming caused by humans increases at a rate of 0.2 °C. By comparison, natural causes have a much smaller impact on global warming, with a contribution estimated between -0.1 °C and 0.1 °C every 120 years. The main driver for this elevated human-induced contribution is carbon dioxide ($CO_2$) (Directorate-General for Climate Action [European Commission], no date a).

In order to limit and reduce the emission of $CO_2$, the European Union Emissions Trading System (EU ETS) was implemented in 2005. Most of the European countries participate, and it is the first international emissions trading system in the world. The period from 2021–2030 reflects the fourth phase of the EU ETS, during which the system will be subject to new rules (Directorate-General for Climate Action [European Commission], no date b). These rules are among the determinants that might have contributed to the huge increase in the allowance price per tonne of $CO_2$ during the last two years. Until 2017, the price of $CO_2$ was relatively low, but it is now higher than ever before. The main research question guiding this thesis is stated as follows: "To what extent have the determinants of the $CO_2$ price changed over the last two years?"

An overview of the development of the EU ETS will provide insight into the topic. Subsequently, the new and currently applicable rules concerning the EU ETS will be introduced. Following this, the core topic will be addressed—namely, the allowance market, the price drivers of the demand and the supply for allowances, and the development of the allowance price. Next, a model based on the paper of Bai and Okullo (2021) will be introduced, which reveals the actual determinants of the $CO_2$ price. With the help of this model, it will be clarified whether the determinants of the allowance price have changed or remained the same.

## 2. European Union Emissions Trading System

Today, the EU ETS is one of many cap-and-trade systems that reduce greenhouse gas (GHG) emissions. Basically, these systems function by setting a cap on the total amount of emissions produced by the covered installations. Companies are allowed to trade emission allowances up to this cap, depending on their needs (European Union, 2016, p. 1). The limit on GHG emissions ensures that there is a $CO_2$ price. The limitation of the number of allowances is responsible for its level and for the effectiveness of the EU ETS (Brunner *et al.*, 2009, p. 2).

### 2.1 Phase 1

The first phase of the EU ETS occurred from 2005 to 2007. This initial phase is known as a trial phase for the subsequent period, in which the goals codified in the Kyoto-Protocol had to be met. In order to fulfil commitments regarding the reduction of GHG emissions, the system initially built up an infrastructure to simplify the control and monitoring mechanism over the companies concerned (European Union, 2015, p. 7).

Before the first period started, the 25 EU member states (at that time) were required to create and submit National Allocation Plans (NAPs) to the European Commission. These NAPs included a national emissions cap, an allocation of the emission allowances, and the total amount of the allowances issued (Böhringer and Lange, 2012, p. 13). The emission caps were set before the start of the first period based on estimates by the participating member states. The need for allowances was overestimated (European Union, 2016, p. 1). Since the beginning of the first phase, about 2.1 billion emission allowances (EUAs) were allocated annually to 11,000 installations covered by the system. Free allocation was the basic allocation principle. Moreover, it was possible for firms to trade allowances at no costs within the EU. Every year by the end of April, companies were required to submit the allowances to the European Commission for realised emissions from the past year. As allowances were distributed to firms in March, firms had the choice either to bank and use them for the subsequent year or use them for the current year (Hintermann, 2009, p. 5).

Towards the end of the first phase, many companies still held some remaining allowances. However, the emission allowances lost their value due to the oversupply and could no longer be used for the next phase (Directorate-General for Climate Action [European Commission], no date b). Moreover, it was forbidden to take the certificates from the first phase to the second phase. In order to prevent individual companies from emitting more $CO_2$ than they submit allowances for, a penalty of 40 euros was introduced for each excessive tonne of $CO_2$ emitted during the first period (Hintermann, 2009, p. 5).

Due to rejections and ongoing debate, much time passed from the submission of the NAPs by member states to the approval of these NAPs by the European Commission. The national (and thus decentralised) allocation of allowances was a laborious and extensive process. The process was so backlogged that the last NAP was only approved 18 months after the start of the first phase. Due to the national regulations, the EU ETS at that time could be described as an amalgamation of 25 systems (Ellerman, Marcantonini and Zaklan, 2016, pp. 91–92).

### 2.2 Phase 2

The second phase of the EU ETS ran for five years, between 2008 and 2012, which corresponds to the first commitment period of the Kyoto-Protocol. The intention was to continue to improve the processes and developments initiated by the first phase so that the reduction of GHG emissions determined by the Kyoto-Protocol could be achieved (European Union, 2015, p. 7).

Compared to the initial phase, the number of members grew from 25 to 27 EU member states and 3 non-EU countries. The quantitative limit on allowances has been reduced from 2.1 billion tonnes of $CO_2$ to 1.9 million tonnes of $CO_2$. The Linking Directive implemented the allocation of international credits to firms, which were created by two Kyoto-Protocol mechanisms—the clean development mechanism (CDM) and joint implementation (JI)—to support the companies in their commitments to the EU ETS. At the beginning of the EU ETS, only the credits from the CDM could be used next to the EUAs. Another change compared to Phase 1 was the inclusion of the aviation sector from 2012 onwards. In order to take more restrictive action, the penalty for emitting more than allowances were submitted increased to 100 euros per tonne (European Union, 2015, pp. 18–19).

Two features of the first phase have led to considerable debate. The first feature was the free allocation of allowances, which resulted in windfall profits for covered firms by the system. The second disputed characteristic of the EU ETS was the national rules for allocation that led to competitive distortions. Even though several people in the European Parliament favoured the auctioning of allowances, the decision was made to allocate 95% of the allowances freely in the first phase and 90% in the second phase. These incredibly high percentages of free allocation were an incentive or gift to countries for participating in the EU ETS. The solution for both problems was the auctioning of allowances. The plan was to implement the auctioning step by step, so the development of EU-wide, sector-specific standards was required to reduce the competitive distortions from ongoing free allocation of allowances (Ellerman, Marcantonini and Zaklan, 2016, p. 92).

### 2.3 Phase 3

The second commitment period under the Kyoto-Protocol corresponds to the third phase of the EU ETS, which occurred from 2013 to 2020. Previous periods provided a great deal of information, insights, and experience for the third phase, which placed priority on harmonizing the system (European Union, 2015, p. 7). In order to address this main concern, several important adjustments were made. The national caps were merged into one EU-wide cap, which declined annually by 1.74%. Furthermore, the European Emissions Trading Scheme was expanded. In addition to the new member Croatia, new sectors such as chemical and aluminium were brought into the system (European Union, 2015). With the expansion of the coverage of the EU ETS, a link to other cap-and-trade systems could be facilitated in the future (Ellerman, Marcantonini and Zaklan, 2016, p. 91). Moreover, from 2013 onwards the allocation of allowances in the electric utility sector was based on auctioning. For the rest of the industrial sectors, auctioning was expected to replace 70% of the free allocation by 2020 and to replace it completely by 2027. Thus, free allocation prevailed during the third phase for some sectors and was determined by benchmarks (Ellerman, Marcantonini and Zaklan, 2016, p. 92). By this process of benchmarking, the installations were compared with other installations based on their performance. The average 10% of the most efficient installations were part of the benchmarks and received all required allowances for compliance to EU ETS commitments for free. However, it became necessary for less efficient installations to reduce their emissions or buy additional allowances to cover their emissions with allowances. In this way, a more accurate distribution of emission allowances was feasible (European Union, 2015).

First and foremost, free distribution is still maintained because there are companies in the non-electric sectors that are threatened by international competition (Ellerman, Marcantonini and Zaklan, 2016, p. 92). For example, if companies had to pay for emitting $CO_2$ in the EU and the emission was free outside the EU, then these companies would consider relocating because of the cost disadvantage. This situation is referred to as 'carbon leakage'. The consequences of some firms moving outside the EU are unemployment and unreduced GHG emissions. Firms that are at risk of considering a relocation are listed on the so-called 'carbon leakage list'. This list contains all the companies that receive allowances at no cost as a way of preventing this carbon leakage from occurring (Erbach, 2014, p. 4).

Until the end of 2013, supply and demand for allowances diverged for the following reasons:

- Economic crisis reduced production and thus the need for allowances, while the supply did not change.
- Allowances were freely allocated from the beginning of the EU ETS.
- The system faced alternatives to the EUAs such as international credits.
- Complementary policies led to increased reduction of emissions.
- The European Investment Bank sold 300 million allowances.
- The development of climate regulations and participants' expectations impacted the market.

While reduced demand and international credits as factors for the divergence between supply and demand for allowances are acknowledged, the impact of the complementary policies is often debated. As a consequence of the previously listed drivers, a surplus of 2.1 billion allowances was accumulated. Considering that the oversupply of allowances is not part of the open market, the only way to eliminate the surplus is by decreasing the provision of allowances in the future. To reduce or slow the increase of the oversupply, auctions in the third phase of the EU ETS have been postponed. This measure is called 'backloading'. In total, around 900 million of allowances were not auctioned between 2014 and 2016. This amount was not cancelled but was scheduled for inclusion in auctions from 2019 to 2020. This intervention had only a temporary effect and thus became a frequent point of discussion (Erbach, 2014, pp. 4–6).

Because of the divergence between supply and demand, the European Commission reformed the EU ETS with the implementation of the market stability reserve (MSR), which was introduced in 2019 (Perino and Willner, 2016, p. 1). The MSR will be discussed more fully in the next section.

### 2.4 Phase 4 and the MSR

In order to reach climate neutrality in the EU by 2050 and reduce GHG emissions by a minimum of 55%, some adjustments were made for the fourth phase (2021–2030) of the EU ETS. Free allocation continues to be used as an allocation principle during this period; however, it is restricted to the sectors at the highest risk of carbon leakage. The allowances are allocated at no costs to these sectors. For companies in sectors where the risk of relocation is not elevated, free allocation will decrease from 30% to 0% between 2026 and 2030. Furthermore, new and growing installations will be supported by partly receiving allowances for free. A total of about 6 billion allowances are expected to be distributed at no cost throughout the fourth phase (Directorate-General for Climate Action [European Commission], no date c).

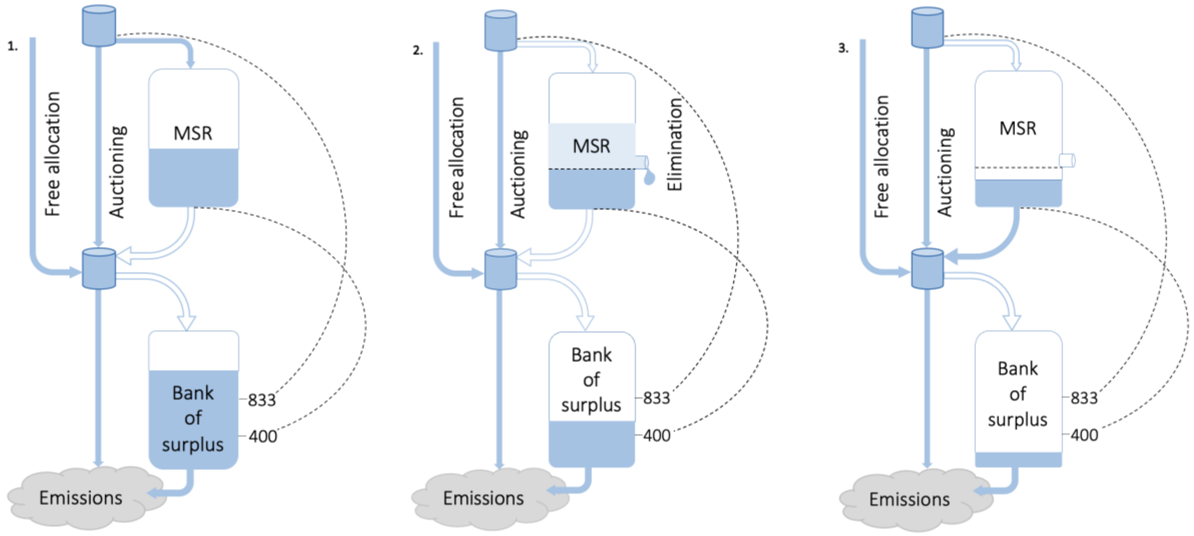
As the main adjustment for the fourth phase, the new MSR rules will completely change the characteristics of the EU ETS. These rules were announced in 2017 and approved by the European Parliament in February 2018. Basically, the main change consists of a replacement of the fixed EU-wide cap with a function that is dependent on the market (Perino, 2018, p. 262).

From 2019 onwards, the MSR has been active together with the adjustments determined in 2017. The MSR delays the allocation of allowances depending on the surplus of allowances across the market. It is reminiscent of the backloading measure from the third phase, except that this is now an autonomous version. All else being equal, the scarcity of allowances is increased in the short term through the MSR; in the medium term, however, the allowances return to the market from the MSR so that the exact opposite is achieved. In the long term, the new version of the MSR has an influence on the limit of allowances, which becomes a function of past and future results of the market, even if in the near future it will be operating as a fixed cap again (Perino, 2018, p. 263).

In Figure 1 the functioning of the MSR is shown by means of three scenarios. The bank of surplus refers to the number of unused allowances in the market. This virtual surplus is bound to two thresholds: the upper threshold with 833 million allowances and the lower threshold with 400 million allowances. From these thresholds, two dashed lines lead to two exits, which open depending on the filling of allowances in the bank of surplus (Perino, 2018, p. 263).

The first scenario is a representation of the situation experienced in 2020, in which the upper threshold of surplus was exceeded. If this is the case at the end of a year, then for the following years there will be an annual reduction of the amount of allowances auctioned by 24% of the banked surplus (Perino, 2018, p. 263). After 2023, the annual reduction factor will decrease from 24% to 12% (Perino, 2019a, p. 340). Until the surplus falls below the threshold of 400 million unused allowances, the number of allowances issued through auctions is reduced. The allowances held back from the distribution are added to the MSR. In 2019, the first allowances were stored in the MSR on the basis of the realised surplus towards the end of 2017 (Perino, 2018, p. 263).

Figure 1: Three scenarios of the MSR



*Author's representation based on Perino (2018), Fig. 1.*

In the third scenario, filling the bank of surplus was reduced below the threshold of 400 million allowances. This situation could occur close to the end of Phase 4. As long as the quantity of unused allowances is less than the lower threshold, there will be an annual transfer of 100 million allowances from the MSR through auctions back to the market. This will continue until there are no more allowances stored in the reserve. Between 2019 and 2020, the 900 million allowances withheld in the third phase were not returned to the market as planned. Instead, they were allocated to the MSR (Perino, 2018, p. 263).

The most relevant feature of the new rules agreed on in 2017, which is also responsible for substantially changing the EU ETS, is the introduction of a threshold for the MSR. This boundary could be applicable in 2023 and can be seen in scenario 2 and 3 of Figure 1 as the dashed line within the MSR. This can be understood as a constraint to the storage of the MSR, which is established by using the number of allowances auctioned in the prior year—around 57% of the annual cap. All allowances exceeding this dynamic level are being eliminated. This situation is depicted in scenario 2, with the lighter coloured area being forced to be cancelled. The estimates assume a cancellation of around 1.7 billion allowances (Perino, 2018, p. 263).

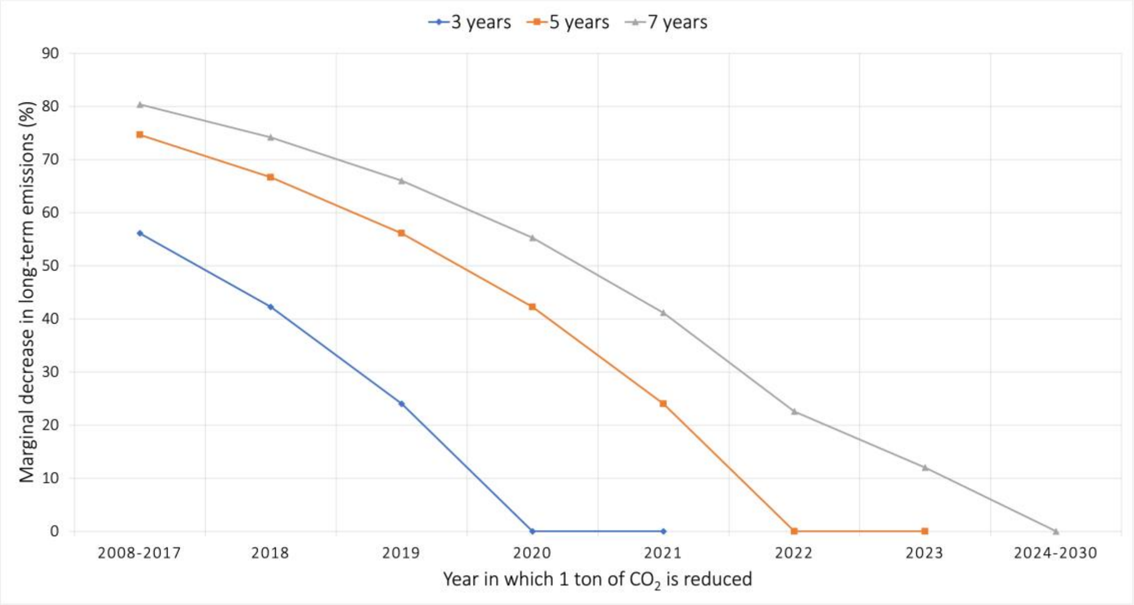
Sometimes members of the EU ETS not only adhere to the EU-wide policy, but also pursue individual policies (Perino, Ritz and van Benthem, 2019, p. 1). These overlapping climate policies were an issue before the introduction of the adjustments to the MSR, as they influence only the ones that are emitting and not the total amount that is emitted. This effect is also known as the ‘waterbed effect’. To best understand this effect, imagine a waterbed and its distribution of water, which changes as soon as someone moves or touches the waterbed. Although the distribution of the water changes, the amount of water remains the same (Perino, 2018, p. 262). Explained in relation to emissions, this means that with further reduction efforts, such as additional climate policies, overall emissions are not reduced, since the total amount of emissions is set by the fixed emissions cap (Rosendahl, 2019, p. 734).

The method of removing allowances from the market impacts how the EU ETS functions, as it causes a puncture to the waterbed. Cancellation of allowances relies on two variables. The first variable is the number of allowances stored in the MSR, which in turn relies on the time the surplus falls below 833 million allowances. The second variable is the moment the quantity of unused allowances falls below the lower threshold of 400 million allowances. The first variable defines the number of allowances risking cancellation and the second one specifies the number of those being saved from it. All else being equal, one more transferred allowance to the MSR leads to an additional cancellation (direct effect); based on how many allowances are held by the MSR, a greater number of allowances can be removed if it takes more time for the surplus to drop below the 400 million threshold (indirect effect). The indirect effect is driven by the declining cap. If fewer allowances are allocated via auctions, the surplus drops faster below the threshold of 400 million allowances and thus fewer allowances are being cancelled. When allowances are returned to the market through the MSR, as in scenario 3, the storage of reserve allowances decreases annually by 100 million, while the boundary for the elimination decreases only by about 30 million allowances. According to Perino, the indirect effect can be neglected for the next assertions, because it is relatively small. This also applies to demand shocks, which could be able to change a decreasing trend in the number of banked allowances into an increasing trend (Perino, 2018, p. 263).

The puncture to the waterbed does not last long. The moment the surplus exceeds the upper threshold (or the lower threshold if the indirect effect is not neglected), the long-term cap returns to be fixed and the waterbed has no hole. The puncture is also effective for past phases of the EU ETS. The number of allowances transferred to the MSR relies on the surplus reached towards the end of 2017 and the years following. Starting with Phase 2, it was allowed to bank allowances from one phase to the subsequent phase. Following this, the supply of allowances was always higher than the demand for them. The cumulative effect of reducing an additional tonne of $CO_2$ on the abatement of long-term emissions is depicted in Figure 2. The cumulative effect only varies with the number of years the MSR obtains allowances and is not dependent on whether the abatement took place in 2008 or 2017. One more unused allowance causes an increase in the number of allowances transferred to the MSR by 0.24 allowances (0.12 after 2023) in the first year. The formula for the second year is (1-0.24) x 0.24 = 0.1824 (Perino, 2018, pp. 263–264).

Three scenarios of the cumulative effect of an additional tonne reduced on the abatement of long-term emissions for Phases 2-4 are illustrated in Figure 2. Three, five, and seven years represent how many years the MSR received allowances. The marginal effect on the long-term cap from 2018 onwards declines each year until the impact is irrelevant. With this effect converging to zero, the waterbed effect returns to its old strength. This means that the changes to the MSR diminish the effect significantly, especially for past reduction efforts and with a smaller effect for future efforts (Perino, 2018, pp. 263–264).

Figure 2: Cumulative effect of an additional tonne reduced on the abatement of long-term emissions for Phases 2-4



*Author's representation based on Perino (2019a), Fig. 2.*

Perino argues that due to the new rules, the waterbed effect is punctured in the short-term. This suggests that with additional reduction efforts made within a short time period, cumulative emissions can be reduced. According to Rosendahl, two issues raise questions about Perino's argumentation. The first issue relates to the reduction efforts and their time span. Only with long-term and not short-term reduction efforts will the waterbed effect likely be re-established. The second issue relates to reduction efforts that are made at a later time as these will not reduce—but will instead increase—cumulative emissions (Rosendahl, 2019, p. 734).

Perino replied to the criticism from Rosendahl by noting that timing is fundamental for the elimination of allowances. If abatement efforts are made, when the MSR no longer receives allowances, total emissions could be increased; however, the magnitude of the effect relies substantially on variables influenced by uncertainty. Furthermore, Perino agrees with Rosendahl by noting that future reduction efforts caused by an additional policy (next to the EU-wide policy) could potentially lead to an increase in total emissions. This would occur by inducing a decrease in the price of allowances, which would in turn reduce the abatement driven by the ETS, reduce the surplus, and lower the number of eliminations (Perino, 2019b, p. 736).

The analysis presented by Perino, however, is based on a low quantity (1 tonne of $CO_2$), which is abated at a specific moment and only includes direct effects, neglecting indirect effects that arise from the development of the price of allowances. Consequently, the impact of permanent reduction measures and possible increase of cumulative emissions are not captured, if reduction through overlapping policies takes place after the MSR is no longer obtaining allowances but prior to the surplus converging to zero, as described by Rosendahl. Once emissions reduction occurs before the MSR no longer receives allowances, there is an increase in the expected removal of allowances. Anticipated emissions reduction after the bank of surplus is empty has no effect on current prices and thus on eliminations because the intertemporal arbitrage ends with the bank of surplus being depleted. Rosendahl focuses additional attention on the time between these periods, which is reasonable and legitimate. In so doing, this strengthens the view that the timing of abatement is of utter importance for the transformed EU ETS (Perino, 2019b, p. 736).

The conclusion of this section is a critique of the current policy mix of the EU ETS. Current rules dispose of low transparency with respect to endogenizing overall emissions in a cap-and-trade system. It appears that the only purpose behind the complex functioning of the EU ETS is to keep scholars occupied. A reduction of the complexity could easily be achieved by linking the supply of allowances to the price, which results in an upward-sloping supply function that all market participants are familiar with from other experiences in the markets. In this way it would be less like a tax than a minimum price on allowances, and it could hence avoid the EU's unanimity rule with higher probability. A dynamic cap consisting of past and future market outcomes is sensitive; however, rules need to be straightforward, and their effects should be possible to anticipate so that all market participants can prepare themselves early and react accordingly. Although these mechanisms can surely be found, the rules for the fourth phase do not include them (Perino, 2018, p. 264).

# 3. Market of allowances

The trading of allowances has the aim of reaching an emissions target at the lowest possible cost by matching marginal reduction costs over all firms. Firms that are trying to maximise profit will always choose the most affordable option between reducing emissions and buying allowances on the market. An allowance price is efficient if it offsets the reduction cost of emissions by one unit under the emissions limit, which is also known as the ‘marginal abatement cost’. This translates into the need for reliable EUA prices that contain all information about the costs of emission reductions to meet the cap so that efficient reduction decisions can be made (Hintermann, Peterson and Rickels, 2016, pp. 108–109).

If the allowance market is efficient, the price for an allowance will be the result of supply and demand. Policies such as the fixture of the emissions cap are the main drivers of the supply of allowances. As decisions on the quantity of allowances supplied mainly influence the price level, the next section covers the determinants of the demand for allowances (Hintermann, Peterson and Rickels, 2016, p. 109).

## 3.1 Price drivers on the demand side

On the demand side, the determinants of the allowance price can basically be divided into two groups. One group determines business-as-usual (BAU) emissions and the other the marginal abatement costs (Hintermann, Peterson and Rickels, 2016, p. 109).

The demand for allowances is mainly driven by the realised BAU emissions in the covered sectors of the EU ETS. These emissions are in turn affected by economic growth, the energy efficiency of the economy, and the carbon-emission intensity of the economy. In the short term, they are also influenced by changes in the weather, which in turn have an effect on the demand for heating and cooling and the generation of electricity through renewable energies. For example, it was unusually dry in Scandinavia in 1996, and emissions in Denmark nearly doubled. This was because Denmark had to export carbon intensive coal-based power to Sweden and Norway instead of importing free $CO_2$ hydropower from those countries (Hintermann, Peterson and Rickels, 2016, p. 110).

The allowance price is also driven by the abatement possibilities and their associated costs. Two reduction options were preferred during the second phase of the EU ETS: process optimisation and investment in energy efficiency. Since these investments influence the price level of allowances and not how the allowance price fluctuates on a daily basis, research has concentrated more on the abatement possibility of fuel switching. Fuel switching refers to the switch from gas to coal-fired power generation or vice versa, depending on which one is less expensive. On a temporary basis, fuel switching is probably the most important abatement opportunity. Given the characteristics of the electricity sector in Europe, fuel switching is associated with coal and gas. If there is a market with perfect competition, the supply of power providers will be adapted according to the marginal generation costs. The allowance price is equivalent to the cost of emitting $CO_2$ and should imply that power providers make use of fuel switching until the implicit abatement cost is below the allowance price. This implicit abatement cost is also called the 'fuel-switching' price in euro per tonne of $CO_2$. Firms can take advantage of fuel switching internally or directly with other firms that own generators. Fuel switching was especially noted in countries where a high proportion of gas, coal, and oil generation takes place. If the price ratio between gas and coal increases, then this results in an increase in the fuel-switching price, which in turn causes the allowance price to rise to such a degree that fuel switching is, in fact, a significant approach to reducing emissions (Hintermann, Peterson and Rickels, 2016, p. 110).

In all the studies covered by Hintermann et al. (2016), the natural gas price positively influences the allowance price. For the coal price, however, the effect is not quite clear. Certain studies indicate a negative effect of the coal price on the allowance price, while other studies suggest the opposite. Still other studies find no significant effect between the coal price and the allowance price. In empirical studies that attempt to explain the allowance price with the help of energy prices, one price is always used as a representative case for oil, gas, and coal. As the coal market is not integrated the way the gas and oil markets are, power providers could encounter different coal prices in determining fuel switching. A study included in the paper of Hintermann et al. (2016) confirmed that, by using different coal price series, the results in the allowance price dynamics change. This variation could be a reason for the different results regarding the effect of the coal price on the allowance price (Hintermann, Peterson and Rickels, 2016, p. 111).

A large part of the literature suggests that observed fundamental factors influence the allowance price; however, changes in the allowance price dynamics cannot always be explained. To account for variation in the allowance price over time, most studies include dummy variables. However, these studies do not take uncertainty into account, which affects several price determinants. Especially, fuel prices and other observable price drivers are characterised by uncertainty. Unpredictable demand fluctuations imply that BAU emissions are also stochastic (i.e., randomly distributed). This indicates that the price of allowances should represent the expectations of market participants in terms of the scarcity of allowances, taking the corresponding uncertainty into account (Hintermann, Peterson and Rickels, 2016, p. 113).

Unexpected jumps in the supply and demand of allowances can be smoothed by banking and borrowing allowances. These jumps are shocks, for example, that are caused by a rise in energy demand, which is in turn induced by more heating during a cold period or the requirement for more energy supply triggered by a short-term increase in wind power. Such shocks are presumably compensated for by other shocks with the opposite effect in the future. They are also called ‘mean-reverting’, because as they deviate the allowance price from a long-term average in the short-term, and at some point they will return to the same level of this average. Mean-reverting shocks do not impact the cumulative amount of emission reductions needed to meet the long-term emission cap. This means that their influence on the allowance price varies based on the banking rules. Studies have revealed that if banking from one phase to another is prohibited, then towards the end of a trading phase variations in the determinants have a greater impact on variations of the allowance price. This is due to the fact that it will be more and more unlikely that a temporary shock will be compensated for in the remaining phase by another shock with the opposite effect. From the start of the second phase of the EU ETS, the banking of allowances was permitted from one phase to the subsequent phase. Allowances banked from a previous period can be used to react to a temporary increase of emissions. As firms would thus be borrowing from themselves, this is also referred to as ‘quasi-borrowing’. The positive number of unused allowances in the second phase made the borrowing constraint irrelevant while moving to the third phase. Banking and quasi-borrowing are responsible for the application of the marginal abatement cost theory to the cumulative anticipated reduction cost, instead to the daily reduction decision. This is because banking and borrowing should be able to cancel out the effect of such strong deviations on the cumulative expected allowance demand, as these deviations are neutralised over time (Hintermann, Peterson and Rickels, 2016, p. 113).

Finally, it is possible that electricity, fuel, and allowance prices are simultaneously driven, which has led several researchers to explore the long-term relationship between energy and $CO_2$ prices by means of the cointegration analysis. In contrast to methods that interpret fuel prices as pre-established determinants of the price of allowances, a cointegration analysis considers all prices as endogenously determined. If prices are cointegrated, then they appear to have a common trend between them. The fact that one has found cointegration does not mean that there is effectively a long-term relationship among the prices (Hintermann, Peterson and Rickels, 2016, pp. 111–112).

### 3.2 Price drivers on the supply side

The mixed results in explaining the allowance price could be due to inefficiencies in an immature market. At the same time these findings could result from the impact of certain economic, institutional, and technical factors on the price level instead of the price dynamics. Hence, this section focuses on the allowance price level (Hintermann, Peterson and Rickels, 2016, p. 116).

Often surveys are based on the assumption that there is a stable relationship between the determinants of the demand for allowances and the allowance price. As the interaction among BAU emissions, reduction amounts, and allowance prices is anything but simple, it is probable that this assumption does not hold. To further clarify this, imagine an economy-wide marginal abatement cost (MAC) curve, which rates the various emission reduction options by their reduction costs. The method applied to ensure a one-tonne decrease of the emissions under the emissions cap is also referred to as ‘marginal abatement technology'. The gap between BAU emissions and the emission cap determines the amount of reduction required, which in turn influences the abatement method. The amount that needs to be reduced relies on several variables, including input prices. For example, if the price of natural gas changes, this can affect both the marginal abatement cost of a particular technology and the BAU emissions. Both can be affected because of the switch from one input fuel to another, thereby marginalising a different reduction technology. This suggests that the marginal effect reported in most studies represents two effects: a relative price effect and a quantity effect. The relative price effect implies a shift in the level of the MAC curve, and the quantity effect results in a movement along the MAC curve. The quantity effect might be irrelevant when trying to estimate the temporary effect of marginal changes in price determinants (under the assumption that marginal technology does not change), which does not favour the ability to predict the impact of nonmarginal changes. For instance, if the EU were thinking of a reduction of the emissions cap for the future, the prediction of the allowance price from several studies would become almost useless; this is because, under a newly introduced emission cap, the relevant reduction technologies that fix the allowance price might have changed from the old equilibrium. Regulatory announcements regarding the level of the cap have been found to have an impact on the allowance price in the first and second phase of the EU ETS. This confirms the importance of quantity effects. Since the expectations of market participants are not observable and possibly inaccurate in retrospect, it might not be feasible with this ex post analysis to make a prediction about the price level in reaction to planned adjustments of the expected abatement amount or costs (Hintermann, Peterson and Rickels, 2016, p. 116).

With the possibility to bank allowances between phases, it is increasingly the overall long-term cap rather than the phase-specific cap that drives the development of the allowance price. In the absence of uncertainty, efficiency means that companies reduce their emissions and store and lend out allowances, causing the price of allowances to rise with the interest rate. The price level for allowances is connected across various time periods through banking and borrowing, such that companies are able to smooth their reduction costs over time. The quality of the smoothing of abatement costs is not influenced by uncertainty; however, uncertainty may increase the incentives of firms for banking, in case they want to hedge against emission risk. The costs of hedging would be higher if banking and borrowing were not allowed. Towards the end of the second phase, allowance prices were positive, reflecting the accumulation of allowances by market participants for the third phase, as they anticipated a reduction in allowance supply for the coming years. Expectations concerning the future situation of the market and the risk premium needed to store allowances are both embodied in the allowance prices (Hintermann, Peterson and Rickels, 2016, p. 117).

To conclude this section, in principle every policy that influences emissions from installations or sectors covered by the EU ETS is expected to impact the demand for emission allowances and, consequently, allowance prices as well. This is especially the case for carbon or energy taxes and measures that enhance energy efficiency and renewable energy (Hintermann, Peterson and Rickels, 2016, p. 117).

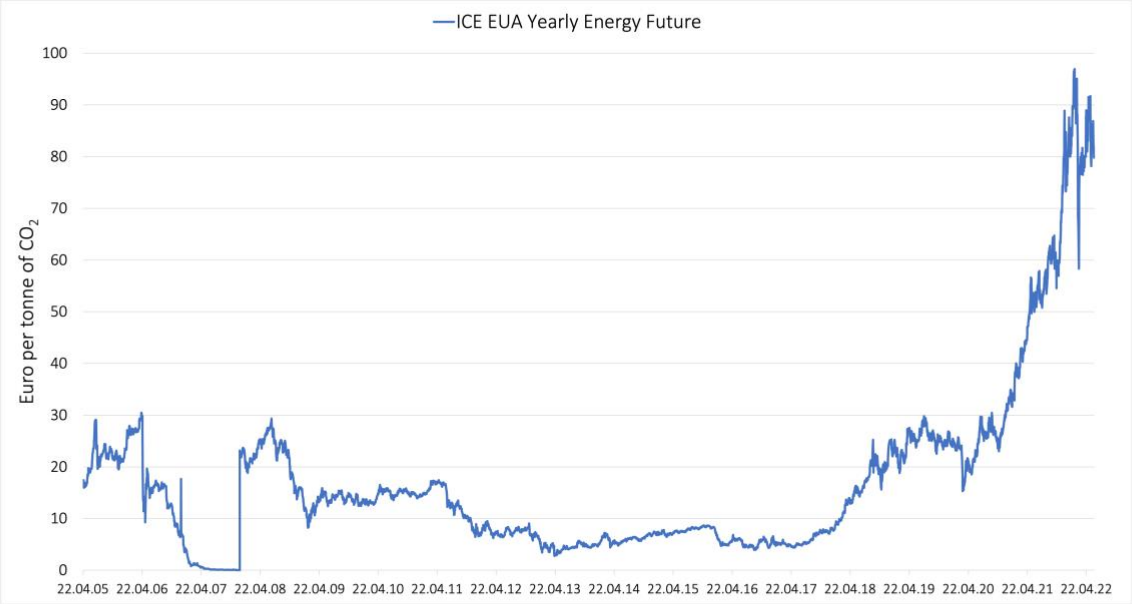
### 3.3 Development of the allowance price

Allowance prices developed contrary to the expectations of market participants during the first phase of the EU ETS. In the initial phase, there was neither knowledge nor experience about the functioning of the market; therefore, the emissions cap was fixed at a high level, which in turn had led to the anticipation of low prices. Figure 3 uses the ICE EUA Yearly Energy Future to illustrate the development of the daily allowance price. The future was created on April 22, 2005, which is shortly after the EU ETS started operating. Nevertheless, the increase in the price can be observed from the starting value of the future until April 2006, when it crossed the 30-euro mark. Within a few days, the allowance price collapsed to less than 10 euros. Subsequently, the price increased again and stayed for roughly four months near the 15-euro mark before it declined to zero by mid 2007 (Hintermann, 2009, p. 6).

The collapse of the allowance price can be explained as a result of the first emissions accounting, also called emissions verification, whereby the realised emissions in 2005 were confronted with the emissions cap. The outcome of this first round of emissions accounting revealed that the realised emissions were 94 million tonnes less than the emissions cap had allowed. The subsequent round of emissions verifications led to no changes since the price was still around zero. During the first phase, realised emissions were always below the emissions cap. Firms have either tried to over-abate, or the emissions cap was fixed too generously. Since banking the allowances to the next phase was not permitted, a greater reduction of emissions than was required to use leftover allowances for the subsequent phase can be excluded. An initial analysis indicated that abatement also impacted the deviation of realised emissions to the emissions cap (Hintermann, 2009, pp. 6–7).

With the start of the second phase, the EUA price rose from around zero to over 20 euros per tonne. Subsequently, the price reached nearly 30 euros before crashing to below 10. This crash was probably due to the financial and European debt crisis. After recovering from the crisis, the allowance price fluctuated around 15 euros until early 2011 (Bai and Okullo, 2021, Fig. A.1). Following the Fukushima disaster in March 2011, Germany decided to phase out nuclear power by 2022 (Kunz and Weigt, 2014). This could be one of the reasons for the abrupt decline until the end of 2012, which left the EUA price at seven euros. In the first year of Phase 3, the allowance price remained practically at this level until it started to fall to less than five euros. This drop might be in connection with the backloading proposal from the European Commission. Following this, there was a positive trend in the EUA price, which reached its peak towards the end of 2015 (Bai and Okullo, 2021, Fig. A.1).

Figure 3: Development of the EUA price



*Data obtained from Thomson-Reuters Datastream.*

The 21st meeting of the Conference of the Parties (COP) took place in Paris from 30 November to 13 December, 2015. The COP resulted in the adoption of the Paris Agreement, in response to the ever-growing problem of climate change. The aim of the agreement was to limit the negative consequences and risks of global warming by containing the global average temperature below 2 °C above pre-industrial levels (United Nations, 2016). The announcement of the Paris Agreement might also have affected the allowance price when it dropped at the beginning of 2016 to a slightly higher level than five euros. Afterwards, it remained near this low level until mid 2017, before rising again to the 25-euro mark in September 2018. During this time, there were votes on the adjustment of the MSR, which could have contributed to the steep increase of the EUA price (Bai and Okullo, 2021, Fig. A.1). Furthermore, the reform of the EU ETS was announced in April 2018, which apparently increased the credibility of the system (Ampudia *et al.*, 2022).

The most extreme increase of the EUA price took place at the beginning of 2021 with the start of the fourth phase of the EU ETS. The price increased from around 30 to over 90 euros per tonne. According to the European Commission and other participants in the

EUA market, several factors are responsible for this huge increase. For example, the weather was colder than expected in early 2021, which increased demand for energy. Given that production cannot be adjusted in the short-term production, an increased demand for energy can directly lead to an increase in the need of allowances and consequently to greater EUA prices. Moreover, the EU ETS was strengthened by the newly announced proposal ‘Fit for 55’ by the European Commission (Ampudia *et al.*, 2022). ‘Fit for 55’ refers to the already mentioned aim of reducing GHG emissions by more than 55% by 2030. The reduction of 55% GHG emissions is referred to the level of GHG emissions in 1990 (European Commission, 2021, p. 1). Another factor might be the declining emissions cap in the fourth phase of the EU ETS and the key adjustments made to the MSR, which will reduce the quantity of EUAs on the market. Perhaps the main factor that drove the EUA price to this high level is fuel switching. As natural gas prices increased, electricity producers switched from the more expensive gas to coal-fired power generation. As coal-fired power generation is more $CO_2$-intensive, this was followed by a rise in the demand for emission allowances, which in turn increased the allowance price (Ampudia *et al.*, 2022).

# 4. Model

This section presents the model for the regression results—a fuel-switching model for emissions reductions. The starting point for the model is a representative power generator active in the electricity, allowance, natural gas, and hard coal markets. The generator can bring about a markup on the electricity price and is thereby aware of the demand function. Nevertheless, the assumption is made that there is perfect competition in the markets for emission allowances and fuel inputs (Bai and Okullo, 2021, p. 6).

It is further assumed, that the generator can only choose between gas- and coal-fired power plants, as the focus is on emissions reduction by means of $CO_2$-based fuel switching. Moreover, it is supposed that there is always enough capacity, which means that the equilibrium production can be maintained and adjustment decisions regarding capacity can therefore be neglected (Bai and Okullo, 2021, p. 6).

The generator produces electricity with the optimal switch between gas- and coal-firing technology. In order to fulfil emissions-control requirements, the generator must surrender as many allowances to the regulator as emissions were realised during a period. For the submission, allowances are either purchased from the market or taken from the respective storage of banked allowances. If the generator has unused allowances stored, it is possible to trade them on the market for profit (Bai and Okullo, 2021, p. 6).

The current prices of electricity and allowances are known, whereas their future prices are unknown. The uncertainty in electricity prices could be due, on the one hand, to inaccurate knowledge about future variations in residual electricity demand. On the other hand, the uncertainty in the allowance price can be caused by regulatory and policy shocks or the actions of speculators (Bai and Okullo, 2021, pp. 6–7).

As mentioned previously, the generator is familiar with the market demand curve, and it can therefore trigger a markup in the electricity price. However, the size of the generator is irrelevant in relation to the allowance market and the amount of fuel supply. Thus, input prices are regarded as given. In equilibrium, the cumulative supply of allowances is equivalent to the cumulative emissions cap, which is guaranteed by the companies' expectations regarding the growth rate of the allowance price (Bai and Okullo, 2021, pp. 7–8).

Four equations provide the framework for how the model is derived. One of these equations is a profit function, which the generator seeks to maximise. This set of equations can be solved through stochastic dynamic programming that results in a single equation. The described relationships and assumptions in this section and some additionally required calculation assumptions, followed by several computation steps, lead to the following baseline regression derived from Bai and Okullo (2019):

$$p_t^x = \beta_c p_t^c + \beta_g p_t^g + X_t \beta + e_t$$

This linear regression forms the basis of the model. The variable t denotes the time in weeks. The allowance price is denoted with $p^x(t)$. The natural gas price and coal price are represented by $p^g(t)$ and $p^c(t)$ respectively. X(t) is a vector of dummies, that tries mainly to control for seasonal fluctuations. The variable e(t) represents an exogenous shock with a mean of zero, which is assumed to possess adequate properties for large samples (Bai and Okullo, 2019). The above regression will test whether the allowance price is driven by the gas and coal price. Theory suggests a positive (negative) impact of the gas (coal) price on the allowance price (Bai and Okullo, 2021, p. 12).

### 4.1 Consistency of the estimation

There are some challenges that need to be dealt with when estimating this regression (Bai and Okullo, 2021, p. 13). Non-stationary prices follow a process, which disposes of an unstable probability distribution over time. This means that if two sequences from different points in time of a time series are considered, then the joint-probability distribution of the two sequences differ from each other (Wooldridge, 2018, p. 367). Moreover, as already mentioned in a previous section, a long-term relationship between the prices is unlikely to exist, if cointegration is not found. The challenging part under non-stationarity and non-cointegration is that statistical inference on otherwise untransformed data is insignificant as a result of spurious relationships. Another challenge involves using ordinary least squares (OLS) in the context of heteroscedasticity and autocorrelation, since the estimator is inefficient under these conditions. This might bring about the false acceptance of a null hypothesis. Finally, it becomes a challenge if fuel and allowance prices are endogenously driven because, in that case, OLS is biased and inconsistent (Bai and Okullo, 2021, pp. 13–14).

If prices are differenced, non-stationarity is overcome. However, through differencing, information on long-term relationships gets lost, which might lead to different estimates among levels and among increments. Fortunately, by first differencing, a consistent estimation of the underlying relationship is still possible, provided that the postulated relationship in levels is properly specified and no endogeneity is present (Bai and Okullo, 2021, p. 14). To estimate the influence of natural gas and coal on the allowance price, the OLS estimator is used not only on log-differenced prices, as Bai and Okullo (2021) report in their paper, but also on differenced prices and prices in levels without differencing. Log-differenced and differenced prices are basically log returns and returns, respectively. The formulas for the calculation of the log returns and returns are listed in Appendix A.

Instead of using OLS, Bai and Okullo (2021, p. 14) used the feasible generalized least squares (FGLS) estimator on differenced prices, because OLS is less efficient in the presence of heteroscedasticity. But when the regression in the middle of Table 1 is tested for heteroscedasticity by the Breusch-Pagan test, the results show that the data does not provide strong evidence against the null hypothesis of homoscedasticity (Wooldridge, 2018, p. 270). Thus, the regression with differenced prices should also lead to efficient estimates by using OLS. The idea of taking the log difference of the prices comes from the fact that the variance can be stabilised even more and, consequently, reasonable standard errors can be obtained (Bai and Okullo, 2021, p. 14).

The OLS regression based on prices in levels without differencing faces even more challenges, the first of which is non-stationarity together with non-cointegration. A time-series with a unit-root is non-stationary. There are several ways to test for a unit root. For example, the augmented Dickey-Fuller (ADF) test will test the null hypothesis that a time series follows a unit root. Although conducting the ADF test on differenced and log-differenced prices leads to strong evidence from the data against the null hypothesis, for the conduct with prices in levels, the opposite is the case. This implies that the prices in levels without differencing are non-stationary (Wooldridge, 2018, pp. 610–613). However, non-stationarity is only a problem for the regression results in the absence of cointegration. By use of the Engle-Granger test, the null hypothesis is examined whether the prices are not cointegrated. This is accomplished by performing an ADF test on the residuals of the underlying regression (Wooldridge, 2018, p. 800). The results of the Engle-Granger test reveal that all types of prices used for the regressions are cointegrated. Thus, the first challenge of non-stationarity and non-cointegration is not only handled by differenced and log-differenced prices, but also by prices in levels. Furthermore, heteroscedasticity needs to be considered; unfortunately, this challenge cannot be overcome by prices in levels. Whether OLS or FGLS is used is irrelevant; the presence of heteroscedasticity cannot be neglected. Results from the Breusch-Pagan test confirm that the regression based on prices in levels is highly affected by heteroscedasticity. Therefore, in Section 6 more attention should be paid to the results of the regressions with log returns and returns (Bai and Okullo, 2021, p. 14).

One assumption often used in the literature is the neglect of endogeneity. This assumption will be adopted when exploring the reaction of the EUA price to the gas and coal price. Due to this assumption, the third challenge for the three regressions is also dealt with (Bai and Okullo, 2021, p. 14).

## 5. Data

The data collected for the regressions is standard and frequently used in the literature. It consists of the EEX-EUA 2nd Period Continuous future representing the EUA price, the Title Transfer Facility (TTF) monthly gas futures for the natural gas price, and the ICE API2 CIF ARA monthly coal futures for the coal price. Thomson-Reuters Datastream has been deployed to access the data. The three prices are based on the data type of a settlement price. The EUA price and the natural gas price have been obtained in 'euro per metric tonne of $CO_2$' and 'euro per megawatt hour' (MWh), respectively. By contrast, the price of coal had to be converted from 'U.S. dollar per metric tonne' to 'euro per MWh'. Tables A.1, A.2, and A.3 are listed in Appendix A and contain the summary statistics of the three variables. Future prices instead of spot prices were utilised since the sale of allowances and electricity takes place to a greater extent on forward markets. Furthermore, the greater part of the analysis employs monthly futures (and not annual futures), so that power generation decisions are better captured. The prices are gathered daily; however, the daily data has been weekly averaged for the regression results, which smooths the volatility related to daily data. Instead of selecting a single trading day per week, averages are used to obtain most of the information provided by the time series (Bai and Okullo, 2021, pp. 15–16).

For the regressions, prices are taken on a weekly basis from November 12, 2009 to May 26, 2022. The starting point is in 2009 because the EEX-EUA 2nd Period Continuous future price is only available from this point onwards. This means that a substantial part of Phase 2 (2008–2012), the entire Phase 3 (2013–2020), and the beginning of Phase 4 (2021–2030) are covered. The first phase of the EU ETS was excluded not only because of the time span of the EUA futures, but also because banking from one phase to the next was prohibited in this phase. This, together with a great deal of unused allowances on the market, resulted in a crash of the EUA prices towards the end of the first phase; these developments inevitably led to a decoupling of allowance prices from the fundamentals of fuel switching (Bai and Okullo, 2021, p. 16).

To account for variations in the EUA price, that are not caused by the natural gas and coal price, several dummies are implemented in the regressions: seasonal, shock, and trend dummies. *Seasonal dummies* consist of week, month, and year dummies. These control for variations in the allowance price caused by seasonality in weather, periodic emissions reporting and verification, periodic information disclosures, pattern trading, and phase-specific drivers (Bai and Okullo, 2021, pp. 18–19).

*Shock dummies* are a second type that are implemented. Several studies show that regulatory adjustments and policy announcements regarding the EU ETS significantly influence the allowance price. Hence, controls need to be implemented for such effects (Bai and Okullo, 2021, p. 16). These controls are referred to as 'shock dummies' because they account for all the uncharacteristic price jumps of more than 10% compared to the previous week (Bai and Okullo, 2021, p. 19). The price jumps in the allowance price are shown in Figures A.1 and A.2.

Finally, *trend dummies* are used as well. Figure 4 illustrates the development of the EEX-EUA 2nd Period Continuous future and seven phases of trending. These trends always arise after certain events that are somehow related to the EU ETS. The term 'events' refers, for example, to the publication of new policies and amendments to existing policies or new rules, in addition to events with economic consequences. The first negative trend emerged after the restriction of nuclear energy from Germany. The second trend arose concurrently with the conclusion of the Paris Agreement at the COP21. The third and first positive trend emerged around the voting on the adjustment of the MSR (Bai and Okullo, 2021, p. 17). Before the fourth trend started, the stock market had crashed in March 2020 due to the COVID-19 pandemic (Mazur, Dang and Vega, 2021, p. 1); this was also true of the allowance price, which decreased from 25 to 17 euros. Subsequently, the allowance price recovered quite quickly. This recovery represents the fourth phase of trending. The fifth trend started shortly before the beginning of the fourth phase of the EU ETS. New measures of the fourth phase and the 'Fit for 55' package were responsible, among other factors, for this huge positive trend. The sixth phase is a short negative trend, which emerged immediately after Russia launched its invasion of Ukraine. The last phase of trending is likely to be a recovery trend from the shock of this war. In addition to the reasons listed above, a trend can also be triggered by momentum trading and different capabilities between market participants when it comes to receiving and reacting to information. These seven trends are controlled by trend dummies. Since it is difficult to assess how long the impact of a trend-inducing shock will last, the assumption is made that the effects of the original shock are dissipated when the price reverses or changes its trend (Bai and Okullo, 2021, p. 17).

Figure 4: Development of the EEX-EUA 2nd Period Continuous future price and seven phases of trending caused by an event

*Author's representation based on Bai and Okullo (2021), Fig. A.1.*

## 6. Results

This section presents the results of the regressions, which show the effect of the natural gas and coal prices on the allowance price. Table 1 contains three regressions. The first (from left to right) is the one where the EUA log returns are regressed on the log returns of natural gas and coal. The regression in the middle regresses the EUA returns on the returns of gas and coal. Finally, on the right side of the table, allowance price in levels is regressed on the natural gas and coal price in levels. In each of these regressions, seasonal dummies, shock dummies, and trend dummies are included. The coefficients obtained for natural gas and coal are always significant at least at the 5% significance level.

The results for the log-returns can be interpreted as follows: A 1% change in the price of gas (coal) leads on average to an increase (decrease) of 0.11% (0.09%) in the EUA price. This corresponds to a usual interpretation of an elasticity (Wooldridge, 2018, p. 39). For the regression with returns, this functions in a slightly different way. A 1-euro change in the natural gas (coal) price results directly in an increase (decrease) of the EUA price by 0.099 (-0.093) euro. The same kind of interpretation applies to the regression with prices in levels. Although this regression reveals significant coefficients, it is affected by heteroscedasticity and is therefore only to be taken into account to a limited extent. Despite the fact that the regressions with log-returns and returns have shown that they are not subject to heteroscedasticity, Newey-West heteroscedasticity and serial correlation consistent standard errors have been used in all regressions.

As the shock dummies account for the largest price jumps in the allowance price, the variation explained by the independent variables indicated by the R-squared and the adjusted R-squared is much greater than it would be without them. The R-squared and the adjusted R-squared are also referred to as the ‘goodness-of-fit’. It is reasonable to seek a higher level of goodness-of-fit, but there can also be a danger in overemphasizing it as some factors could be controlled in a regression even when they should not be (Wooldridge, 2018, p. 199). Nevertheless, it is important to include the shock dummies as a way of handling outliers in this case, recalling that OLS is biased and inefficient in the presence of outliers (Bai and Okullo, 2021, p. 19).

Table 1: OLS regression including dummies

| | EUA log returns | EUA returns | EUA price in levels |
|---|---|---|---|
| Natural gas | $0.107^{***}$ | $0.099^{**}$ | $0.306^{***}$ |
| | (0.040) | (0.040) | (0.060) |
| Coal | $-0.087^{**}$ | $-0.093^{**}$ | $-0.472^{**}$ |
| | (0.044) | (0.046) | (0.236) |
| Observations | 655 | 655 | 655 |
| $R^2$ | 0.605 | 0.613 | 0.972 |
| Adjusted $R^2$ | 0.513 | 0.519 | 0.968 |
| Residual Std. Error | 3.742 (df = 531) | 3.674 (df = 526) | 3.231 (df = 577) |
| F Statistic | $6.610^{***}$ (df = 123; 531) | $6.521^{***}$ (df = 128; 526) | $261.377^{***}$ (df = 77; 577) |
| Note: | | $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$ | |

Table 2 shows another set of regression results. The main difference compared to Table 1 is that there are no dummies included in the two regressions. These are purely regressions between the allowance price and the fuel prices. The signs of the coefficients remain the same, whereas the absolute terms increase. It is particularly interesting that the coal coefficients without dummies are larger than the natural gas coefficients, so that the allowance price is more responsive to changes in the coal price. This aligns with the theory that gas-fired power generation is more efficient than coal-fired power generation (Bai and Okullo, 2021, p. 10).

Table 2: OLS regression without dummies

| | EUA log returns | EUA returns |
|---|---|---|
| Natural gas | $0.133^{**}$ | $0.142^{**}$ |
| | (0.063) | (0.059) |
| Coal | $-0.189^{**}$ | $-0.195^{**}$ |
| | (0.089) | (0.080) |
| Observations | 655 | 655 |
| $R^2$ | 0.023 | 0.026 |
| Adjusted $R^2$ | 0.020 | 0.023 |
| Residual Std. Error (df = 652) | 5.311 | 5.237 |
| F Statistic (df = 2; 652) | $7.620^{***}$ | $8.849^{***}$ |
| *Note:* | $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$ | |

It should also be pointed out that the low R-squared and adjusted R-squared are driven mainly by the exclusion of the shock dummies. One advantage and one disadvantage can be drawn from this. As no controls have been included, there is no risk of controlling for factors that should not be controlled for. The disadvantage, however, is that the outliers have not been handled for the two regression results from Table 2, which might lead to a biased and inefficient OLS estimation.

This leads to the conclusion that mainly the results of the two regressions with log-returns and returns in combination with dummies are significant and reliable. The outcome that both gas and coal influence the allowance price is more the exception than the norm. Numerous studies report that allowance prices react to fluctuations in the gas price but not to fluctuations in the coal price. There are even some studies that obtain a positive coefficient for coal (Bai and Okullo, 2021, p. 21). Therefore, it is crucial for the results of the model to include controls for uncharacteristic outlying changes in the allowance price and trend dummies. Without controls for uncharacteristic outlying changes, the significance of the coal price is weakened. Excluding trend dummies decreases the efficiency of the coal estimate. The statistical significance of coal is sensitive, which could be due to its statistical properties, as those influence the precision of a point estimate of an independent variable. To elaborate on this a little more, in the presence of homoscedastic residuals, the accuracy of an independent variable's point estimate is driven by its variance and uniqueness in variation in comparison to other contemporaneous independent variables. If the variation is low in both dimensions, the precision in the estimated sampling distribution of the independent variable's point estimate is diminished. Furthermore, persistence (or high autoregression) is an essential dimension related to time series, which can become an issue in the presence of heteroscedasticity. Therefore, a highly persistent independent variable in contrast to other independent variables receives a larger penalty regarding the standard deviation of its point estimate while modelling or correcting standard errors for serial correlation and (or) heteroscedasticity. This implies that when little attention is paid when modelling the data-generating process of the independent variable, the probability of failing to reject the null hypothesis (even though it should be rejected) is increased (Bai and Okullo, 2021, pp. 24–25).

Tables A.1, A.2, and A.3 show the standard deviations and the variances of natural gas and coal. Coal appears to have less variability compared to natural gas. Since coal prices have a much lower fluctuation than natural gas prices, it is not surprising that the significance of coal is so difficult to obtain. This is because the variance of a point estimate of an independent variable is somewhat increased and could drift to zero with a smaller variation compared to other independent variables; in turn, this leads to a failure to reject the null hypothesis even though it should be rejected. By using controls, this issue has been overcome, and the reaction of the EUA prices to fluctuations in both natural gas and coal prices has been identified (Bai and Okullo, 2021, p. 25).

# 7. Conclusion

Global warming is a problem that must be addressed with greater urgency. The EU ETS is one of many instruments attempting to limit and reduce its effects. In particular, the new rules regarding the MSR seem to be promising and could be effective—even if only in the short term—on the market of allowances. However, an optimal policy mix still needs to be found in order to cancel allowances in the long term and thereby create a certain scarcity. One way to optimise the current policy mix would be to reduce its complexity so that every market participant is able to understand it. This could enhance the market and lead to a more efficient determination of the allowance price.

The $CO_2$ price has never been as high as under the current rules of the EU ETS. As a result, new determinants could play a role in determining the $CO_2$ price. Based on this consideration, the main research question that guided this thesis has been developed: "To what extent have the determinants of the $CO_2$ price changed over the last two years?". To answer this question, a model was introduced based on the model developed by Bai and Okullo (2021). The aim of the model was to obtain a significant positive (negative) effect of natural gas (coal) on the $CO_2$ price. To show that even today in a world with new rules and regulations, a war, or a pandemic, the two fundamental energy prices still influence the $CO_2$ price.

In Section 6, this relationship was found in five regressions. However, three out of those five regressions face challenges such as outliers and heteroscedasticity and could therefore be biased. If a solution to the two challenges could be found in the future, the model would improve significantly. Nevertheless, the regressions with log returns and returns including dummies produced significant results and showed that the variations in the $CO_2$ price can be explained by variations in the natural gas and coal prices. In these reliable regressions, dummies are included to control for movements caused by uncharacteristic changes or trends in the allowance price. The need for dummies to explain the $CO_2$ price can be seen as a limitation of the model, because the triangular relationship should be obtained naturally as in the regressions without dummies. In order to reduce this limitation in the future, some dummies would have to be removed without decreasing the significance and efficiency of the estimate.

Finally, it should be emphasised that significant results were achieved, although this was not possible for many researchers. Moreover, the regressions are carried out on current data, which has certainly not occurred too often so far in the literature. The results obtained in Section 6 lead to the conclusion that the determinants of the $CO_2$ price have not changed in the last two years, as the fundamental factors are still natural gas and coal.

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# A. Summary statistics

## EUA (euro/tCO$_2$); Natural gas (euro/MWh); Coal (euro/MWh)

Table A.1: Summary statistics of weekly averaged log returns

| | n | mean | sd | var | min | median | max |
|---|---|---|---|---|---|---|---|
| EUA | 655 | 0.253 | 5.365 | 28.779 | -25.400 | 0.525 | 18.206 |
| Natural gas | 655 | 0.284 | 6.226 | 38.758 | -47.498 | -0.186 | 38.943 |
| Coal | 655 | 0.276 | 4.458 | 19.871 | -36.690 | -0.050 | 51.374 |

$$EUA\ log\ return_t = LN(Weekly\ averaged\ price_t) - LN(Weekly\ averaged\ price_{t-1})$$

Table A.2: Summary statistics of weekly averaged returns

| | n | mean | sd | var | min | median | max |
|---|---|---|---|---|---|---|---|
| EUA | 655 | 0.396 | 5.299 | 28.081 | -22.431 | 0.526 | 19.969 |
| Natural gas | 655 | 0.480 | 6.356 | 40.399 | -37.810 | -0.186 | 47.614 |
| Coal | 655 | 0.380 | 4.779 | 22.835 | -30.712 | -0.050 | 67.154 |

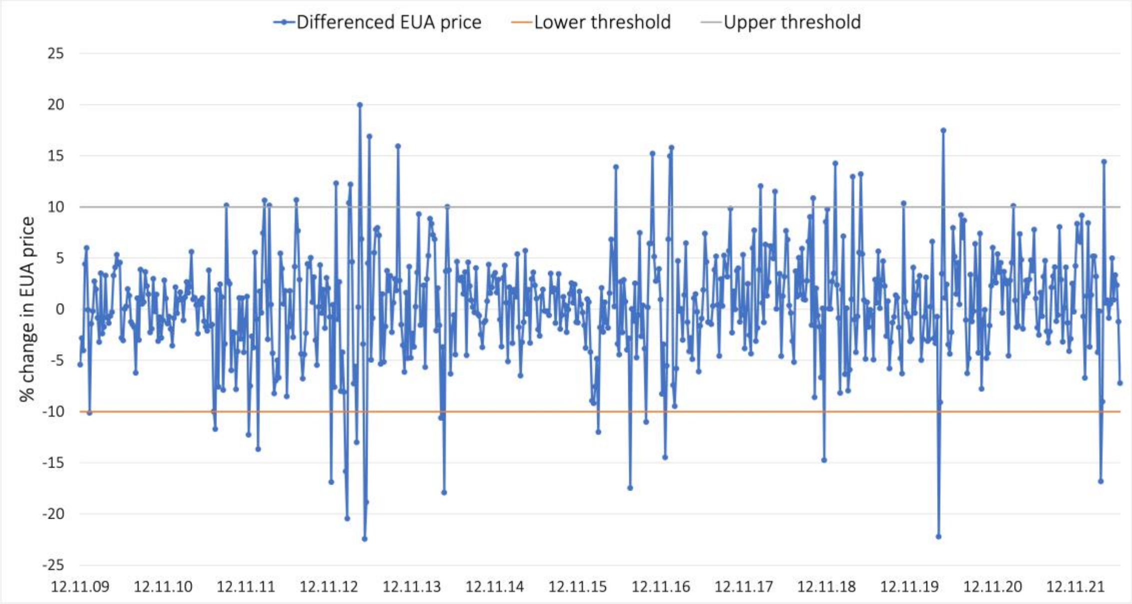
$$EUA\ return_t = \frac{Weekly\ averaged\ price_t - Weekly\ averaged\ price_{t-1}}{Weekly\ averaged\ price_{t-1}}$$

Table A.3: Summary statistics of weekly averaged prices in levels

| | n | mean | sd | var | min | median | max |
|---|---|---|---|---|---|---|---|
| EUA | 655 | 17.477 | 18.181 | 330.535 | 3.014 | 9.832 | 93.918 |
| Natural gas | 655 | 23.831 | 19.307 | 372.757 | 4.140 | 20.276 | 182.200 |
| Coal | 655 | 8.908 | 4.876 | 23.775 | 4.338 | 8.007 | 46.740 |

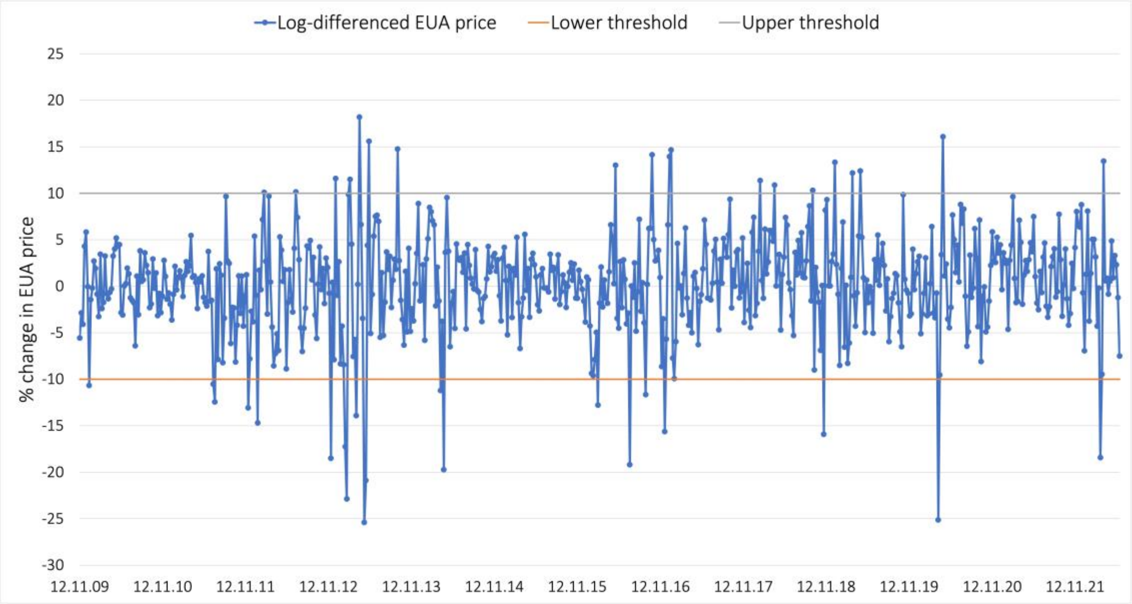
# B. Additional figures

Figure A.1: Percentage change in the differenced EUA price



*Author's representation based on Bai and Okullo (2021), Fig. A.2.*

Figure A.2: Percentage change in the log-differenced price



*Author's representation based on Bai and Okullo (2021), Fig. A.2.*

UNIVERSITÄT BASEL

**STUDIENDEKANAT DER WIRTSCHAFTSWISSENSCHAFTLICHEN FAKULTÄT**

## Plagiatserklärung

„Ich bezeuge mit meiner Unterschrift, dass meine Angaben über die bei der Abfassung meiner Arbeit benützten Hilfsmittel sowie über die mir zuteil gewordene Hilfe in jeder Hinsicht der Wahrheit entsprechen und vollständig sind. Ich habe das Merkblatt zu Plagiat und Betrug vom 22.02.11 gelesen und bin mir der Konsequenzen eines solchen Handelns bewusst.“

Name, Vorname: De Minico, Ciriaco

Ort und Datum: Stein, 13.07.2022

Unterschrift: