UNIVERSITY OF LJUBLJANA
SCHOOL OF ECONOMICS AND BUSINESS

MASTER'S THESIS

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A DYNAMIC IMPACT ANALYSIS OF SELECTED VARIABLES ON ALLOWANCE PRICING IN THE EU EMISSIONS TRADING SCHEME

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AUTHORSHIP STATEMENT

The undersigned AIKEN KAPLER KOVAČIČ, a student at the University of Ljubljana, School of Economics and Business, (hereafter: SEB LU), author of this written final work of studies with the title A DYNAMIC IMPACT ANALYSIS OF SELECTED VARIABLES ON ALLOWANCE PRICING IN THE EU EMISSIONS TRADING SCHEME, prepared under supervision of associate professor Vasja Rant, PhD.

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LIST OF ABBREVIATIONS

sl. - Slovene

ADF – (sl. Razširjen Dickey-Fuller); Augmented Dickey-Fuller

ARDL – (sl. Avtoregresijski model z eksogenimi regresorji); Autoregressive distributed lag

BSVAR – (sl. Bayesova strukturna vektorska avtoregresija); Bayesian structural vector autoregression

CDM – (sl. Mehanizem čistega razvoja); Clean development mechanism

CER – (sl. Potrjena zmanjšanja emisij); Certified emission reduction

CMA – (sl. Konferenca pogodbenic kot sestanek pogodbenic Pariškega sporazuma); Conferences of the Parties serving as the meetings of the Parties to the Paris Agreement

CMP – (sl. Konferenca pogodbenic kot sestanek pogodbenic Kjotskega protokola); Conferences of the Parties serving as the meetings of the Parties to the Kyoto Protocol

CO2 – (sl. Ogljikov dioksid); Carbon dioxide

COP – (sl. Konferenca pogodbenic); Conferences of the Parties

CUSUM – (sl. Kumulativna vsota rekurzivnih rezidualov); Cumulative sum of recursive residuals

CUSUMSQ – (sl. Kumulativna vsota kvadratov rekurzivnih rezidualov); Cumulative sum of squares of recursive residuals

DOLS - (sl. Dinamična metoda najmanjših kvadratov); Dynamic ordinary least squares

EFTA – (sl. Evropsko združenje za prosto trgovino); European Free Trade Association

ERU – (sl. Enota zmanjšanja emisij); Emission reduction unit

ESI – (sl. Kazalnik gospodarske klime); Economic sentiment indicator

ETS – (sl. Sistem za trgovanje z emisijami); Emission trading system

EU – (sl. Evropska Unija); European Union

EUA – (sl. Pravica Evropske Unije); European Union allowance

GHG – (sl. Toplogredni plin); Greenhouse gas

HDD – (sl. Ogrevalni stopinjski dnevi ali temperaturni primanjkljaj); Heating degree days

ICAP – (sl. Mednarodno partnerstvo za trgovanje z emisijami); International Carbon Action Partnership

ICE – (sl. InterContinental borza); InterContinental Exchange

IPCC – (sl. Medvladni odbor za podnebne spremembe); Intergovernmental Panel on Climate Change

IPI – (sl. Indeks industrijske proizvodnje); Industrial production index

JI – (sl. Mehanizem skupnega izvajanja); Joint Implementation

LM – (sl. Lagrangov multiplikator); Lagrange multiplier

NAP – (sl. Nacionalni načrt razdelitve); National Allocation Plan

NDC – (sl. Nacionalno določeni prispevki); Nationally determined contributions

NER – (sl. Rezerva za nove udeležence); New Entrants' Reserve

OECD – (sl. Organizacija za gospodarsko sodelovanje in razvoj); Organisation for Economic Cooperation and Development

OLS – (sl. Metoda najmanjših kvadratov); Ordinary least squares

RGGI – (sl. Regionalna pobuda za toplogredne pline); Regional Greenhouse Gas Initiative

TVECM – (sl. Pragovni model kointegrirane vektorske avtoregresije); Threshold vector error correction model

UN – (sl. Organizacija združenih narodov); United Nations

UNFCCC – (sl. Okvirna konvencija Združenih narodov o spremembi podnebja); United Nations Framework Convention on climate change

US – (sl. Združene države Amerike); United States

VECM – (sl. Model kointegrirane vektorske avtoregresije); Vector error correction model

INTRODUCTION

Nowadays, the notion of global warming can be observed everywhere around us. Books, studies, articles all urge the reader to grasp the existential threat posed by climate change and within it, global warming. Out of all environmental externalities, it is the one capable of causing irreversible, uncontrollable damage to our planet and fundamentally challenging societies on a global scale.

In light of these dire scientific predictions, research and policy proposals concentrate on three approaches which may mitigate climate change[1]: first, reducing greenhouse gas (GHG) emissions from the combustion of fossil fuels (with CO2 as a leading problematic gas), second, removing CO2 from the atmosphere or the emission stream with the help of carbon sinks and carbon capture and storage technology, and third, neutralizing the effects of global warming with geoengineering, including controlling solar radiation. The first of these approaches (reducing GHG emmissions) is considered as the singularly crucial approach in regard to climate change mitigation. Given that GHG emmissions are a source of negative externalities that extend not just across countries, but also across generations, putting a price on GHG emissions is necessary if any policy is to be effective in the area of climate change. Putting a price on emissions allows for the negative externality, which is underpriced in the market, to be adjusted by a price increase (Nordhaus, 2019).

The price increase on GHG emissions, or CO2 in particular, is either done through a tax imposition on CO2 emissions (a so-called carbon tax) or through limiting the quantity of allowable emissions and creating an emission trading market (so-called cap and trade) (Nordhaus, 2019). The latter approach is used in numerous emission trading systems (ETSs). The first such system was the one established by the European Union (EU) in 2005 with the purpose of making the system functionable by 2008 in order to aid EU Member State countries in achieving the international targets of the Kyoto Protocol (European Commission, 2015).

The Kyoto Protocol, however, is not the only important international agreement that pressures the parties to achieve the desired objectives in regard to climate change. One of the earliest agreements was the United Nations Framework Convention on climate change (UNFCCC), which was agreed upon in 1992, and even today represents the central international treaty on combating climate change. Its goal was very clear – to restrain hazardous man-made intervention into the global climate since the dawn of the industrial era. It is the main framework treaty because it extends to 198 parties, which were present at the Convention (European Commission, n.d.a). However, the first universal and legally binding global climate deal was adopted at the Paris climate conference in late 2015, where

[1] In addition to mitigation, there are also several initiatives that follow the path of adaptation to climate change.

over 150 countries agreed on keeping the global temperature under 2°C and trying their best to limit it to 1.5°C in comparison to pre-industrial levels (European Council, n.d.).

At first look, the Paris climate targets may be perceived as unambitious, yet the current situation proves that impression to be wrong. As an indication – June 2019 was the hottest month ever recorded and the extreme weather conditions are already showing the extent of negative effects (OECD, 2019). Therefore, pricing emissions has become a necessity, given the current outlook of climate change. The ETSs have gained their recognition of being an effective tool in reducing emissions. Due to their versatility of use for various environmental problems, they have become a tool of choice by many policy makers. Nevertheless, they are most commonly used to curb GHG emissions. Policy makers favour ETSs due to the authority it gives them in determining the amount of emissions. The system, however, would not have enjoyed its recognition and effectiveness without also providing benefits for the companies. It is therefore important to note that companies involved in the ETSs can financially benefit from these systems (Bertrand, 2013).

If ETSs indeed provide such an effective way of reducing GHG emissions, ETSs data should in principle exhibit increases in the prices of emission allowances. Since that is not always the case in practice, this naturally leads to the question of what drives the emission allowance price? There is no singular answer to this question. An answer may be inferred from the recognition that the ETS is an almost unique viable option to reduce GHG emissions, in particular CO2, which in turn leads to the question of what influences the price of CO2 and the other GHG gases. Consequently, that can be reformulated into the question what drives the price of emission allowances.

The popularity of ETSs price drivers as a research topic has risen substantially since the inception of the EU ETS. Because the EU ETS was the first trading system of its kind, the data about it is readily available and the literature is extensive. Authors analysing ETSs price determinants usually turn to the selection of variables that are related to natural sciences, but play an important role in policy and social sciences. These include the prices of fossil fuels such as natural gas, coal and oil. As an addition to energy variables, authors also use the price of electricity. Another group of variables deriving from the natural sciences are variables directly connected to weather conditions such as temperature, rainfall precipitation and others. From a purely economic perspective, variables influencing the ETS allowance pricing usually include various market indexes as well as the industrial production index and the economic sentiment indicator. However, the literature could still benefit from observing additional economic variables not directly connected to the natural sciences, but possibly influencing the behaviour of ETSs. One such underexplored economic variable is the exchange rate.

The purpose of this thesis is to establish whether exchange rates affect EU ETS allowance pricing and to add a new perspective on the topic of price determinants. Additionally, the interest and aim also lies in uncovering the strength of relationships between EU ETS allowance pricing and its determinants. The rationale for adding the exchange rate is observed in the study by Su & Deng (2019) with varying effects of exchange rate on carbon emission allowance price in selected provinces in China (Chinese ETS). Moreover, the data on this matter is available in the longest possible time series obtainable due to EU ETS being the first system of its kind, allowing for valuable research with relatively ample data.

My primary goal is to empirically assess the relationship between the selected variables – USD/EUR and CNY/EUR exchange rates, fossil fuel prices, electricity prices, heating degree days index and the EU ETS allowance price. The selected variables fall into the categories of energy, weather conditions and economic connotation. My focus is set on the newly introduced variables to the analysis, namely the aforementioned exchange rates. The aim of this thesis, in more details, is to provide answers to the following four research questions:

1. Do USD/EUR and CNY/EUR exchange rates, fossil fuel prices, electricity prices, heating degree days index significantly affect the EU ETS allowance price?
2. How do - USD/EUR and CNY/EUR exchange rates, fossil fuel prices, electricity prices, heating degree days index affect the EU ETS allowance price?
3. Do the effects of USD/EUR and CNY/EUR exchange rates, fossil fuel prices, electricity prices, heating degree days index differ in the long vs. the short term?
4. Are the effects dependant on the category of the variable (energy, weather, economic conditions)?

The rest of the thesis is structured as follows. The first chapter provides an overview of the development of emission trading with depictions of the three most important agreements on the global climate change action that lead to the implementation of emission trading systems. It also reviews global emission trading by providing a general depiction of ETSs across the world and their respective performances and trends. The second chapter offers a detailed review of key features of the EU ETS as well as description of the main distinctions of past and current Phases. The third chapter provides a literature review of the EU ETS price determinants by individual Phases. Relevant studies are presented. The last chapter is devoted to empirical testing of selected variables in regard to their potential short- and long-run effects on EU ETS allowance price. Data description is provided first, along with description of the methodological approach with depiction of the ARDL model. Finally, results with main findings are presented and compared to the results of other studies. The final point in the thesis is conclusion.

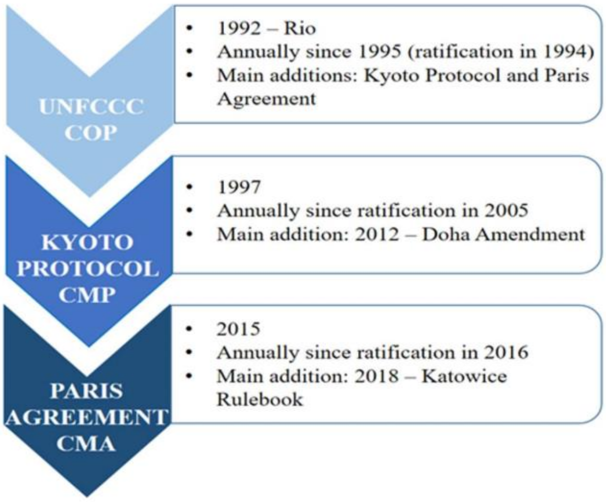
1 DEVELOPMENT OF EMISSION TRADING

Since the most viable opportunity to combat climate change is by decreasing the GHG emissions, the economic perspective of this objective gained substantial relevance. By putting an appropriate price on these emissions, the emissions trading began. However, accommodating an appropriate price poses a challenge even nowadays and has been proven difficult to set. One of the first obstacles to overcome was the problem of having no previous experience on how to deal with setting up the emission price. Moreover, an important question on the topic was also how to price the emissions, namely, by imposing a tax directly on carbon or by facilitating trade of a limited amount of emission allowances (Nordhaus, 2019). To understand the rationale behind each of these questions and their arguments, it is necessary to recognize the importance of timely progression of the climate change debates on a multilateral level. Therefore, I continue with a short but fundamental overview of agreements made by countries around the globe that, inevitably, shaped the course of action in the area of climate change.

1.1 From Rio to Paris

Agreements depicted in this chapter, represent an imperative in global action against climate change. In addition to the primary substance of each agreement, the pacts also serve as a framework for smaller distinctive agreements and amendments.

Figure 1: Progression of main climate summits with conference frequency and main additions



Source: Own work based on the overview of the conferences from Ministry of Foreign Affairs of Japan (n.d.).

As shown in Figure 1, the UNFCCC is the parent agreement that lay the framework for the Kyoto Protocol and the Paris Agreement. The latter two agreements, which serve as the main two additions to the UNFCCC, are on a similar level but with broad distinctions in their policies and particularly in the forms of coping with climate change, which is further described in following subchapters. Each of the agreements resulted in annual conferences held after the ratification. In the case of the UNFCCC, the subsequent conferences are called Conferences of the Parties (COP). Conferences with regard to the Kyoto Protocol are called

Conferences of the Parties serving as the meeting of the Parties to the Kyoto Protocol (CMP) and conferences with regard to Paris Agreement are called Conferences of the Parties serving as the meeting of the Parties to the Paris Agreement (CMA) (Ministry of Foreign Affairs of Japan, n.d.). The main addition to the Kyoto Protocol is the Doha Amendment, serving as a guide for the second commitment period of the Kyoto Protocol. The main addition for the Paris Agreement is the Katowice Rulebook, which is a collection of rules for achieving the Paris Agreement objectives (Cuddy, 2018).

1.1.1 United Nations Framework Convention on Climate Change

Posing as one of the first and most important treaties in regard to coping with climate change problems, the UNFCCC, agreed in 1992 in Rio de Janeiro, delivered a singular but shared goal among the participant countries. Singularity of the goal is observed by its reliance on the one and most important aspect of the Convention, that is to hinder negative, man-made intrusions that have direct or indirect impact on the climate. By acknowledging the goal, the other crucial step in the process was to have the treaty ratified by participant countries. In this respect, the Convention is considered a success, since almost all countries around the globe have ratified the treaty, which in other words means that almost all the world recognizes the problem of climate change. Due to the number of countries ratifying the treaty, amounting to 197 countries, the UNFCCC only entered into force in 1994 (UNFCCC, n.d.a).

Despite the unmeasurable nature of 26 articles of the Rio Convention, they present one of the earliest agreements on the topic of climate change, also in regard to the included definitions to be universally accepted in later agreements. The so-called “ultimate objective” laid out in the second article, provides only an abstract measure of greenhouse emissions to guide any further developments on the topic. It should also be stressed that the objective does not contain any measures to fight or to reverse the effects of climate change but only aims to achieve a certain (stable) level of GHG emissions that the environment is able to adjust to, while not threatening the production of food and allowing for further sustainable economic development (UNFCCC, 1992).

In the following two articles, principles and commitments are depicted in a more detailed manner than the overall objective. Moreover, the treaty further describes all Parties’ obligations in the area of research and observation, education, training and public awareness. The obligations under these articles are not of finite nature but provide substantial freedom, where each country has the possibility to tackle climate change at its own pace and according to its own national capabilities. The subsequent articles lay the structure of further conferences, establish the main bodies and describe their functions. Likewise, additional formal and operational requirements are determined (UNFCCC, 1992).

The reason for this Convention being perceived as a success, lies in the fact that the subject of climate change was not as widely recognized at the time as it is nowadays. Despite generally acknowledging climate change as a problem, the scientific documentation was not in abundance as it is today. Therefore, with ratifying the treaty, countries boosted formal concern and attention towards the matter. At the beginning of Convention's activities, mitigation of climate change was at the forefront, whereas adaptation was left behind. The distinction between the two terms lies in the goal they pursue. Namely, adaptation connotes the meaning of adjusting economic, ecological and social systems as a reaction to the current and potential future climate change and its consequences (IPCC, 2018). On the other hand, mitigation contains all activities that lower the pace of climate change (IPCC, n.d.). With respect to susceptibility to and impacts of climate change participant countries requested greater reassurance and projections. The Third Assessment Report of Intergovernmental Panel on Climate Change (IPCC) in 2001 contributed to the relatively larger emphasis on adaptation (UNFCCC, n.d.a). This report combined different working groups that were able to provide scientifically measurable data on climate change for the past, the present but also make projections for the future (IPCC, 2001). With help of the IPCC Reports, the participant countries also focused on adaptation, which gained its importance by adopting a special Adaptation Committee (UNFCCC, n.d.a).

Additionally, the importance of the Rio Convention is observed in the recognition of all countries' exposure to the climate change effects, regardless of countries' participation at the Convention or their state of development. However, the Convention appeals for proactive endeavour in order to alleviate the effects of climate change. This is particularly important in developing countries, which do not have the means to ease the consequences. With a note to the latter, it is apparent that most of the burden with respect to fighting climate change is assigned to the developed coountries. This perspective was based on the fact that the developed countries, especially the industrialized countries, are those that produce the most GHG emissions. The proposition for these countries was to reduce their emissions to the appropriate levels in their own territory. The countries, depicted as developed countries, are those that are members of the Organization for Economic Cooperation and Development (OECD). Their first task was to lower the GHG emission to the levels of 1990 with a due date in 2000. Not all countries succeeded but the strong stance that they took in combating the climate change was crucial for the success of one of the earliest, far-reaching treaties on the subject of climate change (UNFCCC, n.d.a).

Moreover, the industrialized Parties of the Convention conform to offering their assistance to developing countries in climate change action. The assistance is presented in the form of financial aid to developing countries but is strictly directed at climate change actions. The Convention also established a special scheme, providing loans and grants, which is operated and controlled by the Global Environment Facility. An additional form of developed countries' assistance is technology sharing. This form of assistance is much needed in less-advanced countries, whose economic development is already challenging to accomplish without considering the climate change problematic. Furthermore, with economic advancement in developing countries, it is to be expected for them to have raised the amount of emissions and the Convention therefore, attempts to provide assistance to accomplish the "ultimate goal" (UNFCCC, n.d.a). In this respect, the Kyoto Protocol, which I describe later, offers a resolution for such circumstances.

All participant countries must report on a regular basis about their actions taken in respect to climate change. The developed countries have to report on their annual GHG emissions together with past data from 1990 onward. The developing participant countries have to submit reports in less detailed manner but still have to present clear measures for climate change mitigation and also adaptation to the consequent effects (UNFCCC, n.d.a).

1.1.2 Kyoto Protocol

The Kyoto Protocol is an extension treaty to the UNFCCC, adopted in 1997 and at the time presenting only the second treaty coping with climate change subject on such a large scale. Despite the scope of the UNFCCC in terms of the number of signed Parties and the overall substance of the Convention, it was acknowledged in the year when it came into force that the Convention itself would not sufficiently slow the worldwide growth in GHG emissions. For that reason, the participant countries agreed upon a protocol in the city of Kyoto by the end of 1997, hence the name Kyoto Protocol. The key additions to the Rio Convention, observed in Kyoto Protocol, are the limits of GHG emissions on a set of predefined gases such as carbon dioxide, methane, nitrous oxide, sulphur hexafluoride, perfluorocarbons and hydrofluorocarbons. The Protocol projected measurable reduction of the six aforementioned gases in industrialized Parties and envisioned new forms of instruments as well as provided a market-based system of low cost emission reduction. It is to be emphasized that in the matter of required emissions reductions by industrialized countries, the limits to be achieved became legally binding in 2005 (when entered into force) and not voluntarily pursued (European Commission, 2004).

Beginning with a measurable decrease of GHG emissions in industrialized countries, the emissions were expected to show a drop, on average, of 5.2% relative to the levels in 1990. The reference period during which this reduction was to be achieved was the first commitment period, from 2008 to 2012. During this period, developing Parties were excluded from binding emission reduction goals. Moreover, the reason why a five-year reference period was specified was to provide the industrialized Parties with a feasible goal to be achieved, taking into account the unpredictable elements (e.g. weather), which could, in effect, contribute to vast deviations in emission reductions, in the case if the reference period was to be set at one year (European Commission, 2004).

At the same time, an in-depth debate about the envisioned market-based system for lowering the costs of emission reductions started. The main characteristic of the proposed system was to allow flexibility. The three main mechanisms agreed upon were the emissions trading, Clean Development Mechanism (CDM) and Joint Implementation (JI). The overall market-based system allows for a more flexible and efficient emission reduction at different levels of Parties' engagement. In more details, CDM concerns activities, where no emission reduction goals are imposed and therefore involves developing countries. The JI differs from CDM by concerning activities in countries that do have imposed emission reduction goals. In regard to industrialized countries with legally binding goals, trading of emission allowances was foreseen to take place in order to allow and support not only the trade between them but also to obtain credits for emission reduction activities in foreign countries. The justification behind the three mechanisms is found in the flexibility premise. The primary objective is to reduce the GHG emissions regardless of the place of reduction. This allows for emission reduction where costs are the lowest (European Commission, 2004).

Whereas I provide a more detailed review of emissions trading on a global and EU level later on, I detail the remaining two mechanisms in this subchapter. The CDM provides that emission reduction activities in developing countries acquire certified emission reduction credits (CER), which can be further traded, even by industrialized countries. This allows for flexibility on both sides of participant countries. Moreover, one CER credit equals to one tonne of CO2. To finance adaptation activities, particularly in developing countries vulnerable to the negative consequences of the climate change, the Adaptation Fund is capitalized by a 2% tax that is put on every CER (CDM-UNFCCC, n.d.). On the other hand, JI's purpose is to encourage investment in emission reduction activities. Since JI is linked with emission reduction goals and therefore, linked with industrialized countries and transitioning economies, it is a mechanism that provides with flexibility in achieving the targets. The reward of the emission reduction activities under this mechanism are so-called emission reduction units (ERUs), which can be further traded and thereby aid countries to achieve their emission reduction goals of the Kyoto Protocol (JI-UNFCCC, n.d.).

Kyoto Protocol was revised in 2012 with the Doha Amendment, which updated Kyoto Protocol for the second commitment period, from 2013 to 2020. The Amendment included the nitrogen trifluoride to the six greenhouse gases already covered (European Parliament, 2015). Furthermore, this Amendment will enter into force ninety days after at least 144 Parties deposit their instrument of acceptance. This only occurred on the 2nd October 2020, meaning the Doha Amendment will enter into force by the end of 2020 (United Nations, n.d.).

The key feature of the Kyoto Protocol is that it imposed measurable goals for the participant countries to follow and achieve either obligatory or voluntarily. For that reason, the Protocol set up strict and precise forms of supervision, analysis, verification and compliance arrangements to prevent irresponsibility of the participant countries and to guarantee transparency. Parties have to provide accurate and precise data records of transactions under CMD and JI mechanisms (such as trading CERs and ERUs) to the registry systems, overseen by the UN Climate Change Secretariat, to provide clear and accurate reports on a regular basis and through compliance arrangement, in order to guarantee their emission reductions are met (UNFCCC, n.d.c).

1.1.3 Paris Agreement

Another extension to the Rio Convention was made in Paris in December 2015. In comparison to the Second Amendment of Kyoto Protocol, the Paris Agreement entered into force already in 2016, since the two agreements had different ratification thresholds to enter into force. The Agreement presents an important milestone in the development of international action against climate change. Additionally, it creates a springboard for further and strengthened processes and investments undertaken that are vital for a low carbon future and its sustainability. The essence of the Agreement is in the fact that only now almost all countries are connected to pursue one common aim to counter climate change and adapt to inevitable changes. Besides that, the Agreement also provides for a boost in assistance to developing countries. Thus, the "ultimate objective" of the Paris Agreement is observed in an almost universal action to combat climate change. In particular, the goals are set to maintain the increase of global temperature effectively below 2°C in the current century in comparison to the pre-industrial levels. Even more, the actions are also directed toward keeping the temperature rise below 1.5°C (UNFCCC, n.d.b).

Before delving into the few but far-reaching features of the Agreement, it is important to understand the meaning of nationally determined contributions (NDCs). These contributions present the best efforts of each country to decrease their own emissions and to adjust to the effects of climate change. In other words, the NDCs are to be prepared by each participant country, which then in turn informs the UNFCCC secretariat and maintains adherence to its NDC. The participant countries, should, with their best efforts, implement national mitigation actions in order to reach the set goals. Their implementation intentions and accurate emission reduction data are to be repeatedly reported. Once every 5 years, evaluation of global, cumulative developments takes place. The reason for this evaluation is to observe whether the "ultimate objective" of the Agreement is being achieved and also to communicate additional country-based measures by all participant countries (UNFCCC, n.d.d).

Some aspects of the Agreement are unique and represent a major step forward in mitigating climate change. In addition to the NDCs, global evaluation and the temperature target, a critical point of focus is also set on achieving the so-called global peaking of GHG emissions in order to be able to strike a balance between man-induced emissions and the ability of carbon sinks to remove the GHG emissions in the subsequent part of the century (UNFCCC, n.d.b). The sinks are represented by plants, oceans, soil and more, whereas the sources of emissions include burning fossil fuels, land use with deforestation and more (Thomas, Graven, Hoskins, & Prentice, 2016). Moreover, the Agreement acknowledges non-obligatory cooperation between the participant countries towards reaching their goals, which include transparency, environmental integrity and robust accounting in the case of international transfer of mitigation effects as a consequence of cooperation. The Agreement further set up a system to allow for market- and non-market approaches which aid in supporting the progress towards sustainability (UNFCCC, n.d.b).

With regard to climate adaptation, the Agreement takes a step further by actively undertaking activities towards preparing and realizing National Adaptation Plan[2] and regularly revising communication, clearly depicting priorities, requirements, programs and measures. In this aspect, developing countries are not ignored but are responsible for acknowledging their national situation in the matter of climate change. The Agreement also acknowledges the importance of the negative effects of climate change in terms of loss and damage. It is expected from participant countries to show understanding, preparedness to help other countries, especially, in times of extreme weather conditions or any other potential adverse consequence of climate change. In terms of financing, technology and efficiency-building support, the Agreement advocates for voluntary donations by developed countries. As far as technology and efficiency-building support are concerned, they are aimed at providing help for developing countries but are to be firmly enhanced. Above all, the Agreement aims at reinforcing public awareness, education and more activities on the topic of climate change (UNFCCC, n.d.b).

1.2 Global emission trading

Economics profession had long dealt with pollution (of which GHG emissions are an example of) as a negative externality problem for the environment, the economy and, ultimately, society. The adverse results of excessive pollution occur because polluters do not internalize the social costs of pollution in their business decisions. In the case of pollution with GHG, the markets lack a price on emissions to start with. Because there is no price on (and hence, no immediate business costs of) emissions, the amount of GHG emissions exceeds the optimal treshold that environmental systems could handle.

In particular, the problem emerges from taking decisions that inevitably alter other agents' outcomes without having a market price to accomodate for that. Since no negative consequences are imposed on producers of externalities, there is no motivation for accounting the impact on other agents. Since pollution presents a negative externality, this results in a large discrepancy between private and social cost. Specifically, polluting on an individual level that neglects the wellbeing of others only takes into account the private costs, which results in higher than optimal social cost. In other words, social marginal cost surpasses the marginal benefit of pollution. This implies inefficiency and market failure with excessive levels of pollution following adverse externality (Bertrand, 2013).

From an economic perspective, solving for the adverse externalities of pollution is to set a price on the activities in order to directly influence agents' decisions and make it costly for them to pursue those activities that have a negative impact on the environment. This price can be imposed by two approaches, namely through a cap-and-trade emissions trading

[2] National Adaptation Plan is a process which allows participating Parties to prepare own national adaptation plans to establish medium and long term adaptation commitments as well as formulating and implementing actions focusing on achieving the aforementioned commitments (UNFCCC, n.d.e).

system or by imposition of a so-called Pigouvian tax. Before the advent of pricing emissions, so-called non-market command-and-control approaches were used. They are not in use anymore due to their inflexibility of setting rigid emission restraints on companies and disregarding their in/ability to efficiently conform to restraints. In comparison, the approaches based on pricing emissions, take into account companies' efficiency in achieving the emission targets. Companies choose the amount of emission reductions on a voluntary basis as they compare the price of polluting with their own abatement costs (costs of reducing pollution). From that follows that companies decrese the amount of emissions where it is least costly to do so (Bertrand, 2013).

The first such instrument was the Pigouvian tax from 1920, imposed on railway companies in England. In this example, negative externalities were caused by sparks emission from the engines. Pigou's suggestion was to impose tax on railway companies that varied with the measure of smoke produced. With this proposal, Pigou accomplished the pricing of negative externalities by making companies compensate for the damages. This motivated companies to reduce the amount of sparks to acceptable levels. Thus, even in the presence of adverse externalities, Pigou provided a solution with reinstating market efficiency. On the other hand, theoretical aspect of emission trading began with Coase in 1960 whereas the notion of emission trading was introduced in 1968 by Dales. Coase argued that Pigou disregarded reciprocity of externalities, leading to a failure in achieving an accurate socially optimal level of externality. In particular, prompting producers of adverse externalities to reimburse the losses of other agents, exposed producers of adverse externalities to their losses. Coase called the producers of negative externalities disruptors and those affected by negative externalities victims. By contrast to Pigou, Coase's solution was to set property rights on the emission of externalities. In the absence of significant transaction costs, a socially optimal level of externality can be accomplished by means of negotiation, regardless of which party (disruptor or victim) obtained the property right first. In order to accomplish the socially optimal level, the marginal cost of externality must equal to the marginal benefit of externality. Coase's proposal led to the introduction of market-based instruments such as emission trading systems. These systems gained in popularity due to their efficiency in reducing emissions, accounting for both parties and not focusing on emission reductions uniformly across companies (Bertrand, 2013).

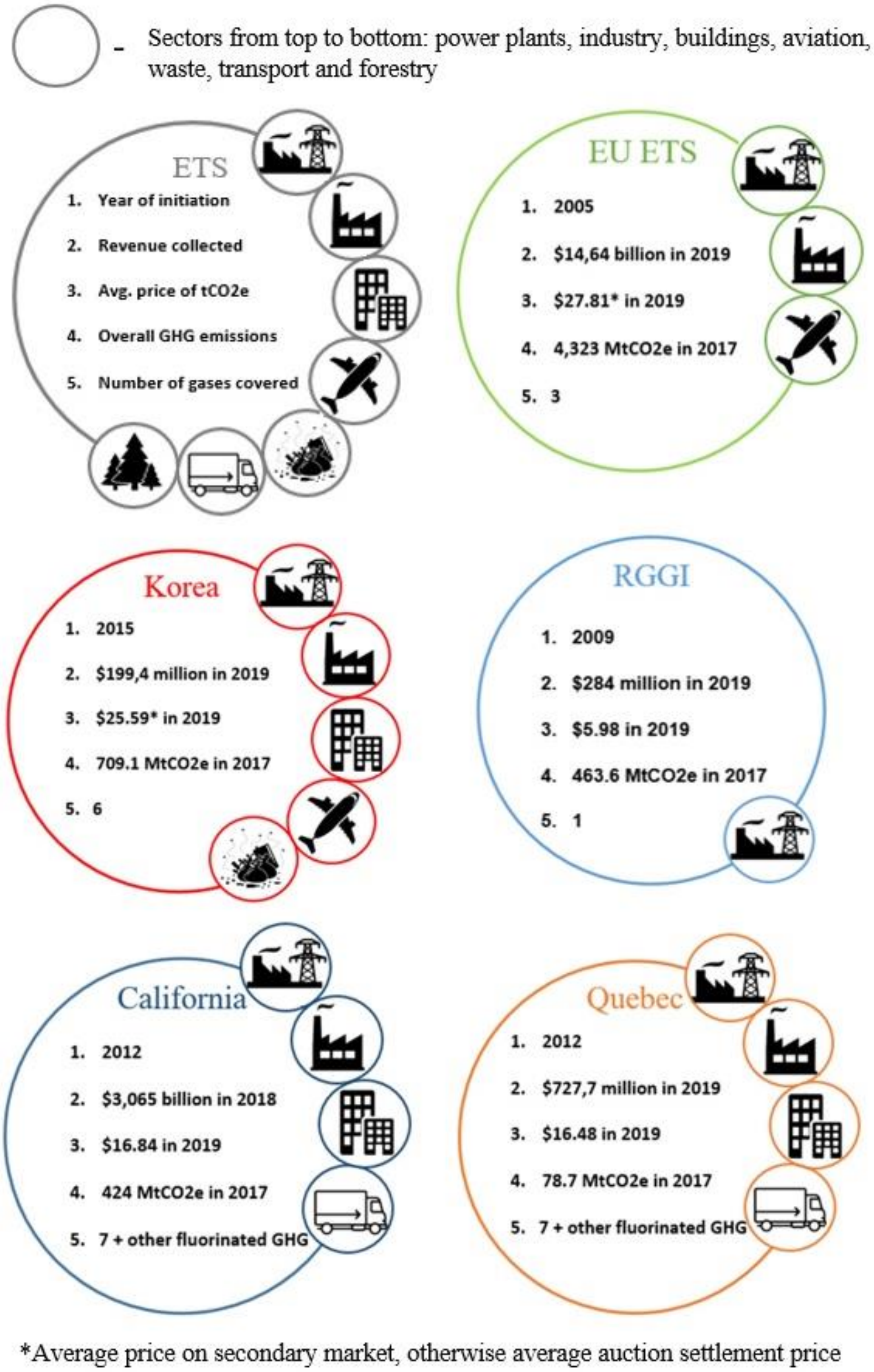
A general upside of ETSs is that they offer a feasible, practical and favourable tool of coping with the problem. ETSs have been used in a variety of environmental matters but specifically with GHG emissions as a global phenomenon. The plentiful positive attributes to legislators and businesses such as flexibility, potentiality of making profits, makes it appealling to the business-side entities as well as providing for direct supervision on the amount of emitted gases to authorities (Bertrand, 2013).

ETSs are the core instrument of achieving a low-carbon economy. As the IPCC emphasized, pricing carbon is a fundamental requirement of climate policies to meet low-carbon economy goals in a most cost-effective way. Despite continuous emphasis on carbon pricing, ETSs already positively influence electrical companies by making coal less favourable option to choose. In example of electrical sector, Regional Greenhouse Gas Initiative (RGGI, currently operational in the USA states – Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, New Jersey, Rhode Island, Virginia and Vermont) showed an almost 50% decline in emissions from power plants since 2008, whereas in the UK, coal-supplied electricity declined from almost 40% in 2012 to 5% in 2018. It is not negligible that carbon price was the essential policy component. Nevertheless, ETSs do not solely benefit power plants but also support diverse industrial sectors to achieve decarbonization. Specifically, from 2017 to 2013, Californian industrial emissions decreased by almost 5% in spite of 17% GDP growth for that same period (ICAP, 2020a).

1.2.1 Diversity of ETSs and the role of supporting policies

As of 2020, 61 carbon-pricing actions across the world are already in place or due for implementation. Out of 61, 31 are ETSs and 30 are carbon taxes. Both approaches comprise for 12 gigatonnes of CO2 or its equivalent, which translates to around 22% of world GHG emissions. Conversely, in 2019, ETSs and carbon taxes in place or due for implementation amounted to 20% of world emissions. The reason behind this increase is vastly due to the trial phase of Mexico's ETS, New Brunswick carbon tax and also the realization of Germany and Virginia ETSs (World Bank Group, 2020).

Figure 2: Largest ETSs across the world



Source: Own work based on data from International Carbon Action Partnership (ICAP) (2020b).

Figure 2 presents infographics regarding the five largest ETSs around the world by the date of entering into force, revenue collected, average price of CO2e, the amount of overall GHG emissions covered, number of gases covered within particular ETS and lastly, the respective sectors covered are presented within the smaller circles. From top to bottom, sectors illustrated are power sector, industry, buildings, aviation, waste, transport and forestry.

Figure 2 further illustrates that sectors and corresponding emissions that ETSs cover are not uniform around the globe. In other words, the inclusion of these sectors in individual ETSs varies. The ETS that covers all the sectors is New Zealand, followed by Chinese pilot ETSs covering domestic aviation, transport, buildings, industry and power. Both ETSs are not included in Figure 2 due to the overall smaller scale or unavailability of most recent information on the amount of emissions covered. The third country with most sectors included is the ETS of Republic of Korea with inclusion of waste, domestic aviation, building, industry and power. Following with transport, building, industry and power sectors are California and Quebec ETSs. The EU ETS covers sectors of domestic aviation, industry and power, positioned at the tail of sectors covered, followed by Kazahstan ETS (not included in Figure 2 due to its smaller scale) covering industry and power sectors and RGGI that covers solely power sector. It should be noted that the ETS discussed are the ones that are already in force and do not include ETS under consideration or development (ICAP, 2020a).

Although ETSs are essential drivers in climate change mitigation, they require additional, supportive policies that focus on wider aspects as well as on narrower, more specific aspects. Some sectors are importantly influenced by innovation, standards, different frameworks and other sector-specific policy rules. Therefore, carbon price, as such, may offer further emission reduction advantages when intertwined with sector-specific measures. A favourable outcome of emission trading is an additional source of government revenues. By auctioning allowances, the government receives revenue that can be purposely spent to finance various climate plans (e.g. renewable energy or low carbon transport). As an example, ETSs auction revenues, invested in innovation programs, may incite more long-term, sustainable development rather than solely assigning the revenues back to the budget itself. EU ETS will dedicate up to €10 billion of auctioning revenues in the next decade to assist innovative technologies in renewable energy, construction, carbon capture and storage activities and many more. Likewise, Quebec's auction revenues are, in vast majority, dedicated to endorsing clean transport and more than half of RGGI auction revenues goes to energy efficiency programs. By the beginning of 2020, all ETSs had obtained $78 billion in auction revenues since 2009 (ICAP, 2020a).

In spite of benefits that ETSs and complementary policies offer through appropriate interaction, administering this interaction is crucial. In particular, a cap that is set in the ETS must account for the complementary policies in order for the ETS not to lose its effectiveness. To cope with this issue, principal policy instruments are market stability measures. In case of the Californian Cap and Trade Program, it functions as a guarantor that will deliver outstanding emission reductions to achieve their 2030 goals in case that projected reductions by means of renewable energy portfolio requirement and low carbon fuel requirement do not completely deliver set goals by 2030. Thus, sectors' specificities and policy mixes may require different ETSs' roles (ICAP, 2020a).

New Zealand reformed its ETS, which is jointly with a comprehensive climate framework (the Climate Change Response Amendment Act) supposed to pave the way for achieving net zero GHG emissions (except biogenic methane) by 2050. In addition, pilot ETSs also offer an insight on reaching decarbonization. China's numerous city and provinical ETSs extend over diverse government levels with linked national and regional programs and targets. The US ETSs are at the forefront in delving with sectoral approaches, focusing on the transportation sector (ICAP, 2020a).

1.2.2 Performance and trends of ETSs around the world

As authorities around the globe ratify challenging mitigation goals and present related policy instruments, national carbon pricing actions have been further encouraged. Numerous cities, regions and countries declared climate crisis in 2019 as the next two years represent critical years for enhancing emission reduction aims of the Paris Agreement. However, COVID-19 and its restrictions made an impact on global economy and consequetly impacted climate initiatives. COVID-19 induced economic downturn that altered consumer behaviour and energy consumption, which tested the economic infrastructure of plenty countries and is still continuously testing the resilience of carbon pricing actions. Additionally, COVID-19 decreased economic activity, which led to a drop in carbon prices in a few ETSs. Moreover, several authorities postponed their acts in strengthening carbon pricing tools and prolonged compliance periods. Importantly, this year's COP (COP 26) and some other meetings were deferred to 2021 due to the pandemic. This only contributes to postponing the ruling about market and international transaction regulations. In spite of the disruption in many fields due to the pandemic, the majority of authorities as well as private establishments advance their work on the climate initiative. In addition, since April 2020 UK, Sweden, New Zealand, Denmark and France put into legislation a pledge to achieve net zero CO2 emission goal, whereas more than 700 companies, 15 investors, 15 subnational regions and almost 400 cities are determined to proceed on work toward net zero emission goals. Bhutan and Suriname present two countries that already achieved the goal and are carbon negative (World Bank Group, 2020).

The trends in carbon pricing show an uprise of authorities that are taking into account other carbon pricing actions that would cover additional emitters to those already accounted for in the established carbon pricing schemes. This has the purpose of supporting measures to achieve the main mitigation goals. In the case of EU ETS members, Luxembourg, Germany and Austria are preparing, at their own initiative, carbon pricing for sectors that are not part of the EU ETS. Furthermore, the scope of current carbon pricing actions is expanding. With additional inclusion of gases and sectors under carbon pricing, levels of emissions are decreasing and therefore, more companies are being monitored in addition to existing initiatives and schemes in New Zealand, Iceland, Chile and Switzerland. Lastly, Europe is, again, discussing taxes on imported goods produced in countries with no carbon tax. This may result in affected countries taking a step forward and introducing some form of domestic carbon pricing actions (World Bank Group, 2020).

Continuing with the Americas, an increase was observed in the amount of carbon pricing actions. One of the front-runners is Canada with its federal carbon pricing concept. Specifically, in 2019, number of subnational actions arised throughout territories and provinces that were integrated with the federal carbon pricing program. In the US, regional carbon market for power sector of Northeastern states, the RGGI, enlarged for two additional states, namely Virginia and New Jersey. Another state considering to join RGGI is Pennsylvania, which would importantly expand the magnitude of the carbon market. Pennsylvania is also a sizeable fossil fuel state. The RGGI also favours cap-and-invest program for the transport sector. On the other hand, Mexico started its trial phase of domestic carbon market in 2020, representing an important milestone for the Latin America as it is the first ETS in the area. However, emerging carbon pricing actions with sector or country inclusion have not been the only highlight of the year. Many collaborations have come to fruition between the authorities in order to coordinate their carbon markets. Beginning of current year signified the cooperation between EU ETS and Swiss ETS. This allowed entities in the EU ETS to use Swiss ETS allowances for compliance and equally for the entities in Swiss ETS to use EU ETS allowances. Moreover, with Brexit, UK will exit EU ETS but is already contemplating to start a national ETS, which would be appropriately connected to the EU ETS (World Bank Group, 2020).

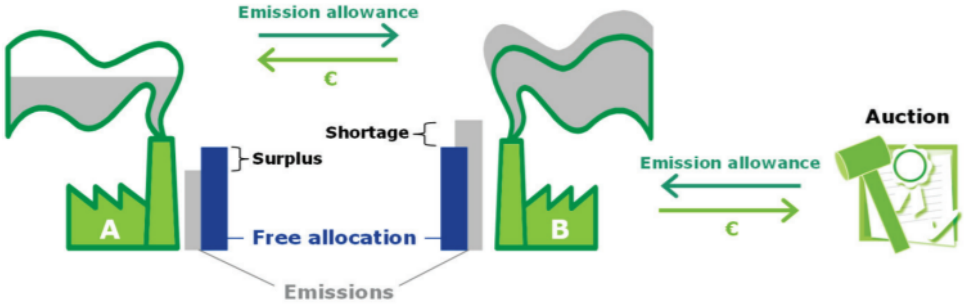
By the end of 2019, carbon pricing produced for more than $45 billion of revenues for governments. Yet, the yearly growth in revenues was lower compared to 2018, which was, to great extent, induced as a result of price stabilization in EU ETS in 2019. The revenue collected was, in a big proportion, purposed for environmental or large development undertakings, whereas another large proportion was directed towards the general budget. The residual part went to direct transfers and tax cuts. Despite substantial progress, carbon prices persist at levels that are still insufficient to be compliant with the Paris Agreement. To reduce emissions in a cost-effective manner and still be aligned with the Paris Agreement goal, prices would need to stand at $40-80 per tonne of CO2 by 2020 and $50-100 per tonne of CO2 by 2030. The figures, however, show that there is a negligible amount of priced emissions within these limits and around 50% of emissions are priced below $10 per tonne of CO2 or equivalent. The global average price of carbon is set at $2 per tonne of CO2, as estimated by the IMF. The overall outlook for the carbon price is that it is still below any acceptable level and has been so for already the past two years. However, many participants are accelerating the pace of decarbonization activities through international collaboration, which is estimated to decrease the costs associated with implementation of caps by almost a half by 2030. In another words, global emissions are supposed to further decrease by half, if collaborations are in place. Even though international collaboration is predicted to have a positive impact on emission reductions, the development on concluding the regulations on the matter and issues associated with it, is sluggish. The reasons for it are multifold, extending from the issues on conversion of Kyoto Protocol credits, tax on transfers of mitigation results to support adaption endeavour in vulnerable countries and ultimately, achieving general mitigation of global emissions (World Bank Group, 2020).

2 EU EMISSIONS TRADING SYSTEM (EU ETS)

The EU always takes a step further with regard to the climate change matters and the ETS is no exception. Before Kyoto Protocol came in force in 2005, the EU had taken all measures necessary to turn one of the three mechanisms, namely emission trading, into reality (European Commission, 2004). Pioneering, however, resulted in a successful start of the scheme, which is also depicted as a first international ETS in the world and has continuously grown over the years (European Commission, n.d.c).

The EU ETS consists of phases. Until today, two phases have already expired and the third one is in force. The Phase I took place between 2005 and 2007 and its fundamental purpose was to test the prices and their development on the market. Moreover, it was a crucial Phase in which the required framework for measuring, documenting and verification of emissions was constructed. The most problematic decision was the amount of the cap, as the pioneering only offered approximations of what it should be. Its fundamental objective was to guarantee a functioning system until 2008 in order for Member States to be able to achieve their Kyoto Protocol obligations. Phase II, which lasted from 2008 to 2012, was, in essence, the first commitment period under the Protocol. Phase III is still in action, starting in 2013 and ending in 2020. Its main target is to improve compliance of the scheme throughout the EU. EU ETS will be essential to accomplish the goals of the second commitment period of the Kyoto Protocol (European Commission, 2015). Post-2020, Phase IV will begin with several novelties in the EU ETS. Firstly, the cap will be decreased by the increase of annual linear reduction factor from 1,74% to 2,2%. Secondly, Phase IV allowances will not be able to cover for Phase III emissions, however, Phase III allowances will be able to cover for Phase IV emissions. Thirdly, aviation allowances can be submitted to cover not only for the emissions by aviation sector but also for the emissions by stationairy establishments. Most prominently, with the beginning of Phase IV, the EU ETS will operate without the UK (European Commission, 2020b).

Figure 3: Presentation of the EU ETS process



Source: European Commission Handbook (2015, page 16).

Figure 3 shows an example of how the system works using an example of two companies, A and B. As can be observed, both companies get the same amount of free allowances at the beginning. In reality, the amount of allowances may not be the same due to different sizes, sectors, etc. However, for the sake of simplicity of the example, the allowance given for free is set to be equal for company A and B. As time passes by, company B emits more GHG emissions than they have allowances. They have two options. Either company B can buy more allowances from company A, which has a surplus and emits fewer emissions than they have allowances, or it can acquire additional allowances at an auction. In the end, companies have to submit emission measurements and sufficient allowances according to their levels of emissions. In case they do not comply to the cap, penalties, and enforcement take place. Penalties are presented in the form of considerable fines (European Commission, 2015).

The quantity of allowances to be auctioned and allocated to Member States, depends on each Member State's share of verified emissions from EU ETS establishments in 2005 or the average of the Phase I period. The highest proportion of emissions is taken into account. This contributes to the allocation of revenues for 88% of all allowances auctioned. Additional 10% is distributed to the least developed Member States to support their reduction in GHG emissions and climate change. The remaining 2% is called the "Kyoto bonus", given to nine Member States, which have decreased their emissions by 20% or more compared to 2005 levels. However, it should be noted that this allocation is only in force for the period 2013 to 2020. For the next period, 90% of auctioned allowances will be allocated according to the share of verified emissions of each Member State and 10% to less wealthy Member States as it is already in the current period. Moreover, 50% or more of the auctioning revenues are to be used for energy and climate related objectives (European Commission, n.d.d).

2.1 Cap and trade system

The EU ETS operates as a cap and trade system. A cap is a limit to the amount of GHG emissions released by establishments. Over time, this cap is supposed to be reduced in order to reduce total emissions. The reduction factor of Phase III is calculated as the average of the overall amount of allowances issued yearly during Phase II. Considering the amount of the cap, companies gain and/or buy or sell emission allowances, which are tradeable. An allowance gives a company the right to emit GHG emissions equal to one tonne of CO_2 or equivalent gas. Moreover, there is also a possibility of buying international credits, although in restricted amounts. The latter is due to the worldwide emission reduction projects. The rationale behind the limited amount of allowances is to guarantee the value of these allowances. Therefore, by having a price on carbon through emissions trading, GHG emissions can be reduced where it is the least costly for companies to do so and investment in low-carbon technologies can be boosted (European Commission, n.d.c).

Furthermore, the advantages of the cap and trade structure are numerous. It is a structure that allows targeting emission reductions with the least cost not just to the companies involved, but also to the overall economy. In comparison to other possible structures and forms of emission reduction, cap and trade systems are the most effective. The command-and-control method puts a definitive ceiling on each establishment, yet it fails to ensure flexibility and may, therefore, create a problem for companies, such as how and where those reductions should take place. The carbon tax is not a viable option in the EU as reduction goals may as well not be achieved and the price of carbon would be difficult to set as different Member States would want a different price for it (European Commission, 2015). The important benefits of the emission trading system are further explained below.

Beginning with the first benefit – cost-effectiveness and flexibility – is derived from the fact that everyone is faced with the same price of emission allowances and those that are able to reduce the emissions at lowest costs can have a benefit out of that. Secondly, there is certainty about the quantity of the emissions that the EU allows in predetermined periods. Sticking to those caps positively supports achieving environmental targets and commitments. Thirdly, revenues that governments collect by auctions of the emissions and fourthly, coming as a result of certainty about the quantity of emissions reduction from establishments liable for approximately 50% of EU emissions, Member States' budget risk is minimized in terms of needing to buy additional international units to meet the obligations of the Kyoto Protocol. (European Commission, 2015).

On the other hand, disadvantages to the cap and trade system exist and are still a part of the debate on problems of the system. With the initiation of Phase III, the cap ceased to be determined on an individual country basis. From this Phase onward, annual linear reduction factors are set for all participant countries in the system jointly (European Commission, n.d.b). Thus, an EU-wide cap is determined. However, since individual country responsibility towards the common cap is not clearly defined, the pressure in this situation is put on negotiations between countries. Kyoto Protocol negotiations suffered for the same reason even before the determination of the general cap and during negotiation on the share of the cap for each country. The reasons for difficult negotiation on emission reduction distribution across countries are twofold. Firstly, achieving "fair" allocation of the negotiated amount of the cap to all participant countries is difficult because not all countries will agree with the particular amount of cap allocated to them. Secondly, a credible cap amount does not guarantee proactive competition of emission reduction between countries. Essentially, countries are not willing to compete among each other in order to reduce more emissions but rather compete to reduce less emissions if another country has already reduced more. Thus, it is unwise to believe the global cap would encourage emissions reduction, when countries perceive it as a constant-sum-game. This further suggest the futility of a global cap to be credible (Cramton, MacKay, Ockenfels, & Stoft, 2017).

2.2 Market participants

The EU ETS accommodates for diverse and abundant number of market participants. Depending on the point of perspective, these market participants can be categorized into two large groups – industrials and financial intermediaries. Each of the group is based either on a sectoral aspect, which is directly linked to their obligatory participation in the scheme – industrial sector, or based on the nature of their business or trading preferences – financial intermediaries (Chevallier, 2012).

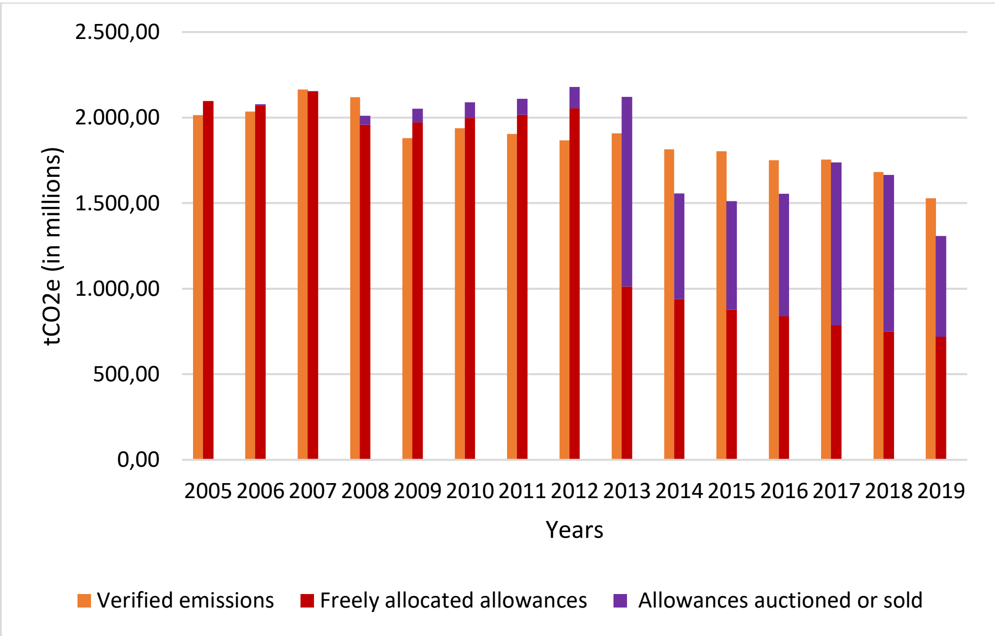
The first group of market participants, covered by the EU ETS based on their sectoral aspect, are industrial sector and energy sector. The latter generate GHG emissions that derive from the production of heat and power by burning fossil fuels. For this reason, they require carbon credits to balance the amount of gases emitted. On the other hand, the industrial sector is not only indirectly involved in polluting due to power consumption but is potentially also involved in direct pollution. In spite of differentiation in both sectors due to their emitting manners, these two sectors are deemed to be so-called compliance buyers as they need to buy credits to compensate for own emissions (Obermayer, n.d.). Furthermore, some literature regards energy and industrial sectors as one joint sector. Past phases of the EU ETS had the allowance market strongly centered toward the power sector, which was observed as a common example of market power on markets trading with emission allowances. This was additionally underscored by the fact that majority of annual distribution was allocated among only a hundred companies (Hintermann, 2011).

The second group of market participant are financial intermediaries. Their part is prominent in allowance trading but can be seen in many market positions. One of their roles is to supply liquidity to the market. Another role is to enable the energy and industrial sector companies to gain access to the market. Lastly, they are responsible for managing a certain share of risks that relate to the nature of emission trading. Financial intermediaries comprise of traders, brokers, investment banks and companies themselves. All of them are market participants with a strict purpose to make a profit and not to cover their emissions. The only differentiation between them is whether they trade allowances for themselves or for their clients. Moreover, the notion of over-the-counter trading and exchanges is important for this group of market participants, since most of them do not represent installations, which are in the position to obtain free allowances (Chevallier, 2012). Nevertheless, with a clear exception of brokers, these market participants present speculators as their principle motive is to directly earn profit from buying or selling the allowances (Obermayer, n.d.).

2.3 Key numbers

Cap serves as a key instrument in the ETS as it represents a pivotal "number" which influences the quantity of allowances, allowance price and ultimately the reduction in GHG emissions. Given that the cap is based on all EU ETS countries and not on individual country anymore since Phase III onwards, the only important metrics for it is presented by the linear reduction factor of the respective Phase. Due to that, the cap itself became a simpler indicator of serving information whether participating countries, jointly, are achieving the intended reduction in emissions.

Figure 4: Volume of verified emissions and total allowances (freely allocated and auctioned or sold) for all countries participating in EU ETS in tCO2e, 2005-2019

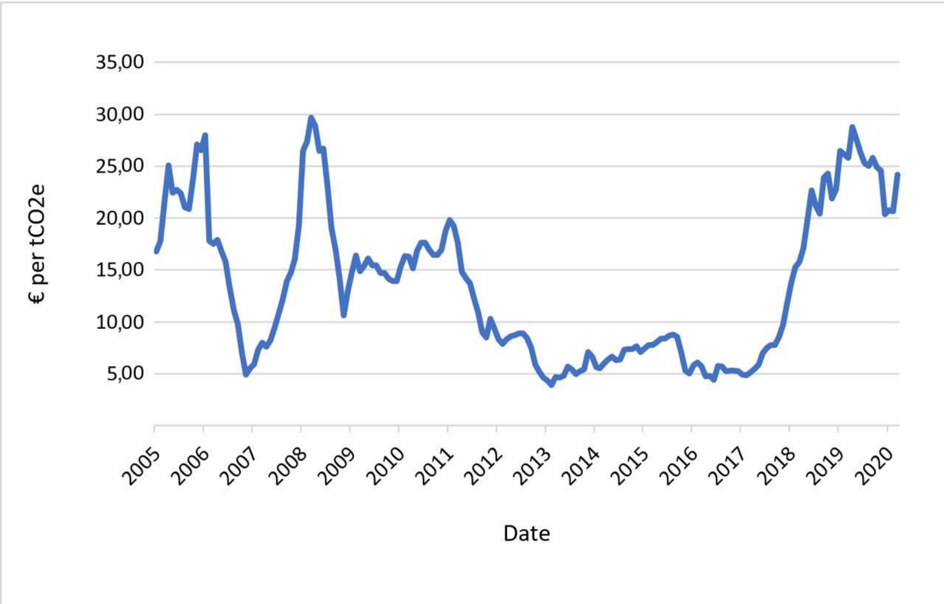


Source: Own work based on data from European Environmental Agency (2020).

The volume of emissions under the EU ETS (without aviation emissions) slowly but surely decreased throughout the years, which is shown in Figure 4. Likewise, Figure 4 depicts for the quantity of total allowances, divided into two parts, freely distributed allowances and allowances that were auctioned or sold. Figure 4 provides an insight on balance between the emission volume that is offset by allowances. As it can be observed, until the beginning of Phase III (with the exception of 2008), an excessive amount of allowances compared to emissions is observed. This resulted in smaller and bigger falls of allowance prices as shown in subsequent Figure 5. However, beyond 2013, a scarcity of allowances started pushing the allowance price upward and the amount of allowances that were auctioned or sold, rose substiantially compared to the pre-Phase III period. The reasons behind this were that auctioning became a primary form of allowance allocation and imposition of various additional rules for allocation and trading (Emissions-EUETS, 2015). It should be noted that the total allowances allocated consist not only of the two parts mentioned but also of correction to freely distributed allowances. The latter is observed to be negligible in its quantity and was therefore left out in Figure 4.

As allowance price represents the core of this thesis and, undoubtedly of the EU ETS, its movement is crucial in understanding the price creation as well as the factors that contribute to the price creation.

Figure 5: EU ETS allowance price dynamics in € per tCO2e from 1.4.2005 to 30.6.2020



Source: Own work based on data from Intercontinental Exchange (ICE) (2020).

Figure 5 shows the price dynamics of allowance prices since its inception in April 2005 until the end of June 2020. An in-depth description of allowance price movement is dissected by each Phase in the third chapter. To provide consistent and simple understanding of the these movements later in the study, I firstly describe main features of the Phases in the following subchapter.

2.4 Development of Phases

In this subchapter, I provide a general overview on EU ETS Phases along with their corresponding primary aims and core novelties. Moreover, as the end of Phase III approaches, additional emphasis on the revision points for the next Phase of the EU ETS is provided.

2.4.1 Phase I

Phase I or the pilot Phase of the EU ETS, started in 2005 and lasted until 2007, inclusively. The primary aim of this Phase was to prepare for the Kyoto Protocol commitment period from 2008 onward. To reach the Kyoto Protocol targets, the EU needed a well-functioning system before the beginning of the Phase II of the EU ETS, which was set to coincide with the Kyoto commitment period. However, at the time, the scheme was limited to the GHG emissions from the manufacturing and power production, which were one of the most emission-exhaustive sectors and in terms of the greenhouse gases covered, Phase I of the EU ETS operated solely on the carbon dioxide emissions (European Commission, 2015). The CO2 emissions during this Phase amounted to approximately half of EU-wide CO2 emissions (Paolella & Taschini, 2008). Another distinct aspect of this Phase is that a vast majority of allowances were distributed to companies without charge. Despite the latter, fines for inadequate balance between the emissions and reduction were already in place and accounted for €40 per tonne of emissions (European Commission, n.d.g).

The outcome of Phase I was a successful formation of allowance price, establishment of an environment to facilitate free trade of allowances and the foundation of the activites required to monitor, report and verify the amount of emissions emitted by the entities under the EU ETS. This was vital for data collection on emissions, trading and necessary for future, ambitious goals from emission reduction's perspective. Nonetheless, it should be noted that the caps for individual countries were based on estimated values, which also resulted in allowance supply that overreached the demand for allowances. Thus, the allowance price plummeted toward the end of the Phase (European Commission, n.d.g). Furthermore, the abundance of supply of allowances also stemmed from the national allocation plans (NAPs). NAPs were based on an individual country’s estimation about the amount of allowances that would be needed for this particular Phase. Since most allowances were given for free, countries inflated the required number of allowances and the EU had to control and often, reduce the national caps. In spite of EU’s reductions in the estimated amount of national caps, the amount of remaining allowances still surpassed their demand (European Commission, n.d.f). Allowances from Phase I could not be traded in subsequent Phases (European Commission, n.d.g).

2.4.2 Phase II

Coinciding with the Kyoto commitment period, Phase II had to deliver factual emission reductions. Therefore, some novelties were presented during this Phase. Firstly, the three European Free Trade Association (EFTA) countries joined the EU ETS, namely Norway, Liechtenstein and Iceland. Secondly, many participating countries introduced nitrous oxide to the system. Thirdly, the EU-wide cap (composed of national caps) lowered in comparison to Phase I cap for approximately 7% and the distribution of free allowances was also reduced by 10%, compared to the previous Phase. Additionally, the penalty set in Phase I proved to be insufficiently high to prevent installations from non-compliance, thus, the penalty per tonne of emission increased from €40 in the first Phase to €100 in Phase II. Despite the higher penalty, installations were able to purchase international credits, which at the time, amounted to 1.4 billion tonnes of GHG emissions. Furthermore, in 2012, the aviation as a sector was added to the system but accounting only for the flights within the participant countries of the system (European Commission, n.d.g).

The emission reductions during this Phase were lowered, partly due to the reduced cap amount based on the lessons learned from the Phase I data on emission reduction. However, emission reductions during Phase II were substantially influenced by the economic crisis that started in 2008. As a result, GHG emissions decreased by a considerably higher amount than primarily anticipated. Due to the effect of the economic crisis, allowance prices were not performing well during this Phase. Moreover, the amount of credits available and allowances as such, were in abundant excess (European Commission, n.d.g). Since NAPs were still defining the overall cap, they suffered a similar problem as in Phase I. Despite the fact that many NAPs had their caps reduced, there were still too many allowances in the system's circulation as a result of decreased economic activity. Due to the reoccurrence of the same problem during Phase II and a few Member States that questioned the cap reductions, an EU-wide cap was established for the forthcoming Phases (European Commission, n.d.f).

2.4.3 Phase III

The primary aim of Phase III was to reduce the amount of allowances each year of the respective Phase. The linear reduction factor of 1.74% for each year was set up based on the larger emission reduction goals of the EU. The latter comprise of overall 20% decrease in emissions and 21% of emission reduction in particular sectors of the EU ETS by 2020, both relative to 2005 (European Commission, n.d.b). In addition to the EU-wide cap, Phase III included several distinctions relative to the previous two Phases.

Firstly, Phase III underwent considerable enlargement of sectors. Among many added sectors dealing with various chemicals, the ones that stand out the most are sectors dealing with chemicals such as petrochemicals, aluminium, carbon storage and more. In practice, the scope of sectors, included in the EU ETS, amounts to more than 11.000 installations that require substantial amounts of energy for their own needs. Foremost, these installations are power stations and different combustion plants such as oil refineries or plants involved with the production of iron and steel, lime, ammonia, different acids and plenty more. These other combustion plants included in the scheme must exceed a certain amount of thermal rated input to be recognized as heavy energy-using installation. Additionally, with abundance of small-scale emitters in numerous sectors, a need for a size exemption from the EU ETS was necessary. Specifically, installations with emissions at such a small scale could experience disproportional costs per unit of emission and were, therefore, permited to opt-out from the scheme but retain their liability to equivalent measures. Small-scale emitters and combustion installations must provide reliable data about below-threshold annual amount of carbon dioxide emitted or below-threshold amount of thermal rated input before being considered as a small-scale emitter or combustion installation, with hospitals being no exeption (European Commission, 2015). With regard to gases that were included in the ETS, among others, aluminium, ammonia, petrochemicals and a variety of acids such as adipic, glyoxycolic and nitric acids were included as well.

Secondly, rather than continuing with free allocation as a preferred form of distribution of the majority of allowances, EU ETS now distributes most of its allowances through auctions. Additionally, over 40% of freely allocated allowances are distributed via the so-called benchmark method, which represents one of the two approaches to free allocation (ICAP, 2020a). Benchmarking requires high quality, readily available data and profound knowledge of industrial processes. Under this approach, companies need to attain certain performance requirements (hence the name of the approach – benchmark) that are established across sector or product level of emission intensity before receving free allowances. This approach encourages early action but may potentially raise equity issues. The other approach is grandparenting, which was used in the previous two Phases. In contrast to benchmarking, grandparenting does not require high quality data and is somewhat simpler. Under this approach, the historical emissions baseline serves as a criterion for allowance distribution. Its main disadvantage is its potential to discourage early trade of allowances because companies can be penalized in early years for investing into emission reductions, which can reduce companies' so-called historical emissions baseline and effectively lead to fewer allowances received (ICAP, 2019). The last major feature of Phase III is a set of 300 million permits that were destined for auctioning to finance formation of innovative renewable energy technologies and carbon capture and storage through New Entrants' Reserve (NER) 300 programme (ICAP, 2020a).

As of 2020, the EU ETS is in its last year of Phase III and literature does not offer a detailed judgement on the Phase's performance, which is largely due to yet incomplete data. On the other hand, thorough negotiations and revision were planned for subsequent Phase. In 2015, proposition for a revision of the EU ETS was already in place and a revised EU Directive 2018/410 entered force in 2018. There are three main points of the revision. Firstly, to strengthen overall system for the period of Phase IV by increasing the annual reduction rate and enhancing Market Stability Reserve to reduce the excess allowances. Secondly, to improve carbon leakage rules by setting focus on the system of free allocation to high-risk sectors (high risk in terms of moving outside the reach of EU ETS) and offering them free allowances, while lower-risk sectors progressively receive fewer free allowances. Moreover, a large quantity of free permits will be set for new and expanding establishments. These allowances will be sourced from the surplus at the end of Phase III and from the Market Stability Reserve. In addition, rules will take into account the possibility of a changing situation through multiple updates to reflect actual production levels. An estimated amount of over 6 billion of free permits will be distributed to the industry over Phase IV. Thirdly, financing innovative technologies and modernising the energy sector is pivotal for the EU ETS. Consequently, two new funds will be established. One fund – the Innovation Fund, will assist in the formation of innovation technologies, wheres the other one – the Modernisation Fund, will contribute towards modernising the energy sector as a whole (European Commission, n.d.h).

3 LITERATURE REVIEW OF EU ETS ALLOWANCE PRICE DETERMINATS BY PHASES

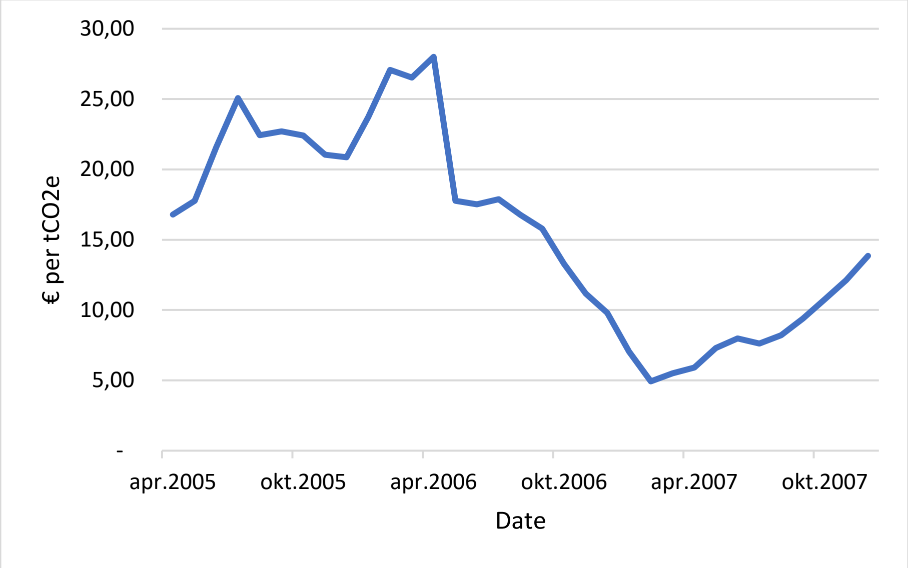
Literature on the topic of EU ETS allowance price creation and price determinants has been the focus of many academics, the EU, other ETSs and other actors. In this chapter, a general framework of allowance price movement is set. Within this framework, relevant aspects of allowance prices are discussed with the purpose of a clearer understanding of price drivers in the subsequent chapters and subchapters. Additionally, I provide an objective review based on numerous studies conducted with purpose of identifiying determinants of EU ETS allowance price. This step is deemed crucial in understanding the EU ETS allowance pricing movement and for subsequent econometric analysis.

With an intention to provide concise overview of relevant studies that are also used for comparison of my results in the empirical part of this thesis, a summary of approaches, time periods, data frequencies and variables used in these studies, is enclosed separately in Appendix 2.

3.1 Phase I

Despite considerable amount of theoretical literature on emission trading dating before the beginning of the EU ETS, research on the topic of emission trading in general and on the topic of emission allowance price drivers in particular, rose after the implementation of the EU ETS. One of the first studies that analysed the effects of different variables on the allowance price was the study by Mansanet-Bataller, Pardo and Valor (2007). Soon after, similar studies were done but opted for spot prices rather than forward prices compared to the aforementioned study.

Figure 6: EU ETS allowance futures price movement in Phase I in € per tCO2e (April 2005 – December 2007)



Source: Own work based on data from ICE (2020).

Figure 6 displays the development of EU ETS allowance price since its beginnings in 2005 until the end of 2007 with considerable fluctuation in the movement of allowance price from almost €30 per allowance in April 2006 to a meager €5 per allowance in February 2007. However, the emphasis is on the fact that Figure 6 shows future prices[3] and not spot prices. Especially in this particular Phase, the understading of spot and futures prices is crucial in order to grasp the various findings of the Phase. Among others, authors such as Alberola, Chevallier and Chèze (2008) and Hintermann (2010), chose to use spot prices in this period due to a smaller trading volume of the allowance futures and due to utilization of data with daily frequency.

[3] Short and long-term maturities of the futures prices are used throughout this thesis due to unavailability of the data with separated maturities, if not stated otherwise.

Figure 7: EU ETS allowance spot and futures prices for delivery in Phase I and Phase II in € per tCO2e from October 2005 to November 2007

Source: Own work based on data from European Energy Exchange (2020).

Figure 7 shows the movements of EU ETS allowance price, distinguished as spot price, futures price with delivery in Phase I and futures price for delivery in Phase II. True distinction of spot and future prices' movement is presented in the study by Trück, Härdle and Weron (2012). In this study, the authors provide an insight for the diverging movement of spot and future prices. Firstly, it should be noted that the moment when futures prices for delivery in Phase II began to deviate from spot prices and futures prices for delivery in Phase I, was April 2006 with widely-spread news of overdistribution of allowances in the EU ETS. After the news came out, spot prices and prices of futures with maturity due in Phase I dropped significantly and became basically worthless in 2007. Authors explain the peculiar movement on the basis of correlation between returns on spot and future contracts. Before emission verification in April 2006, there was a particularly strong correlation between spot and future returns with delivery in Phase I. The futures in this period had maturity due in 2006 and 2007. Spot returns and returns of futures in post-crash period with delivery in Phase II showed, however, lower correlations. This finding is aligned with the fact that futures' prices are much less capricious because they are less affected as their spot counterparts, innuending on future contracts investors' resilience to disappointing short-term events (Trück, Härdle, & Weron, 2012).

Another peculiar movement during Phase I was observed. Hintermann (2010) pointed out that what primarily raised the spot prices to relatively high levels in the pre-crash period remains unknown. A price increase in the pre-crash period was welcomed since prices were expected to be low due to a fairly reasonable cap that was set for the pilot Phase. The cap in this Phase was established based on industry predictions and suffered from an upward bias (Hintermann, 2010).

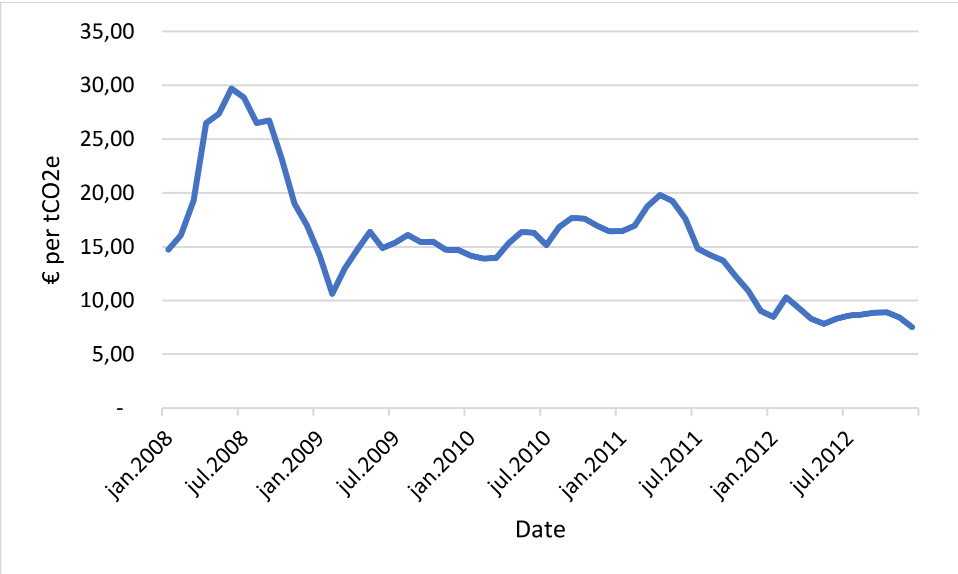
With regard to price drivers, Alberola, Chevallier and Chèze (2008) outline fundamental determinants of allowance prices, using previously identified determinants by Christiansen, Arvanitakis, Tangen and Hasselknippe from 2005. The latter study determined several, distinct drivers of carbon prices, including energy prices, temperature events and policy issues and events. In their study, authors used the Ordinary Least Squares (OLS) approach with two different specifications of explanatory variables, utilizing either extreme temperature with dummy variables of upper and lower quintiles of the respective temperature index or utilizing temperature deviations from seasonal averages. They also used dummy variables for two structural breaks (accounting for news of overdistribution of allowances in April 2006 and the corresponding price adjustment in October 2006), prices of brent oil, coal, gas and electricity. In addition, they included clean dark spread, clean spark spread and switch price, which functioned as a proxy for the abatement cost. Clean dark (spark) spreads represents the difference in peak-hours electricity price and coal price (or natural gas price) in order to generate electricity and corrected for energy yield of coal plants (gas-fired plants). Key take-aways of the study rely on following results: all variables of energy prices with exception of oil price affected allowance price in the full period of Phase I, whereas division of periods in the time frame before and after crash in April 2006 and in various sub-periods, is associated with changing price drivers in terms of significance. This implies change in agents' behaviour due to the announcement of overallocation in April 2006 and in October 2006 due to announcement of stricter rules in Phase II. Additionally, the authors proved that during extreme weather conditions, unanticipated temperature changes affected the carbon price more than temperatures per se (Alberola, Chevallier, & Chèze, 2008). Furthermore, studies by Mansanet-Bataller, Pardo and Valor (2007) and Hintermann (2010) found positive effect of gas price on allowance price, similarly to the results of Alberola, Chevallier and Chèze (2008). The latter two studies found coal prices insignificant in explaining the allowance price, whereas study by Alberola, Chevallier and Chèze (2008) found it significant with negative relationship only in the full period and insignificant in all other sub-periods.

Moreover, a study by Nazifi and Milunovich (2010) was one of the first studies that investigated cointegration in this topic with time period extending from June 2005 to April 2007. The variables they used were the allowance price, fossil fuel prices, daily temperature in Munich and electricity price. Although their study found no long-run relationship among the variables, short-run relationship between electricity price and allowance price was found. However, short-run relationship between allowance price and electricity price was detected and proved already in the earlier studies.

3.2 Phase II

Phase I already set the direction in terms of categories of allowance price determinants to be used in such studies. Namely, fossil fuels prices with switch prices (switch from coal- and gas-based production), electricity price and weather condition variables were often observed in the studies of Phase I. In Phase II of the EU ETS, longer time series became available to researchers and the use of monthly data frequency became prevalent. Taking this and the economic specificity of this period into consideration, studies accommodated for new(er) category of variables applied in the analysis, namely the economic category of variables (mostly stock indexes but also economic sentiment indicator). Furthermore, most of the studies that influenced my analysis accounted for the time period of Phase II of the EU ETS. Moreover, studies began to include data that extends over the two Phases of EU ETS.

Figure 8: EU ETS allowance price movement for futures in Phase II in € per tCO2e (2008 – 2012)



Source: Own work based on data from ICE (2020).

Figure 8 shows EU ETS allowance price movement during Phase II. At the beginning of the period, price increased to nearly €30. Due to a significant economic downturn in 2008 and 2009, the allowance price fell sharply to about a third of its peak value in the period. The allowance price quickly picked up its pace and continued within a range of €15 to €20. By mid-2011, the price decreased by almost a half and hit levels below €10 compared to mid-2008 and declined further in the run-up to the next Phase.

In their study, Koch, Fuss, Grosjean and Edenhofer (2014) focused on allowance price during Phase II and the first ten months of Phase III. In contrast to Phase I studies, the authors used the prices of futures contracts instead of spot contracts and data with monthly frequency instead of daily frequency. The reason behind using futures prices is that almost 90% of allowances in 2011 traded were futures contracts (Kossoy & Guigon, 2012). In their research, variables used for explaining the continuous allowance price deterioration were the switch price (the theoretical price at which electricity producers become indifferent between coal- and gas-fired generation), gas and coal price, growth in wind, solar and hydro production and certified emission reductions (CERs). Moreover, they also included some variables that were somewhat new to this kind of studies, in particular, the inclusion of economic indicators such as economic sentiment indicator and stock market index. The former is an indicator that connects expectations and perceptions of economic activity in the EU and was used as a proxy for economic conditions. Stock index on the other hand, serves as an indicator of present and expected economic circumstances (Koch, Fuss, Grosjean, & Edenhofer, 2014). Although the inclusion of the latter indicator was already observed in several previous studies, economic sentiment indicator was a complete novelty to this area of research. However, due to the particularly worsened global economic situation during Phase II, it made sense to search for additional allowance price determinants.

Koch, Fuss, Grosjean and Edenhofer (2014) found no explicit evidence which would confirm that abatement costs of fuel switching was reflected in allowance prices, which is a rather different result compared to the study of Alberola, Chevallier and Chèze (2008) of Phase I determinants (period before and after compliance break in the spring of 2006). However, the results of both studies for the switch price is coherent in the full period model by Alberola, Chevallier and Chèze (2008). Furthermore, Koch, Fuss, Grosjean and Edenhofer (2014) study does not provide evidence of substantial effects of coal price on allowance price. Additionally, their study's findings with regard to insignificant effects of coal prices and significant positive effects of gas prices on allowance price in two model variations are aligned with the findings of Alberola, Chevallier and Chèze (2008) for periods before and after compliance break in 2006. Moreover, authors find a highly significant positive impact of economic sentiment indicator as well as stock index returns on allowance price. There is also evidence of a negative but significant effect of wind and solar electricity production and CERs on carbon price (Koch, Fuss, Grosjean, & Edenhofer, 2014).

The key extract of the study by Koch, Fuss, Grosjean and Edenhofer (2014) is that concentrating only on the few variables from the areas of energy, environment and abatement may explain only a minor part of allowance price. Therefore, inclusion of various additional economic variables provides for a much broader but relevant aspect in analyses of EU ETS allowance price.

On the other hand, few studies that included data exclusively from the time period of Phase II, investigated cointegration aspect among the fossil fuel prices, electricity price and allowance price. Such studies included in my review are by Peri and Baldi (2011) and Castagneto-Gissey (2013). Studies applied threshold vector error correction model (TVECM) and vector error correction model (VECM), respectively. Both studies presented with findings of long-run relationship among the variables. The difference in both studies is offered in the signs of the variables. Peri and Baldi (2011) found negative long-run relationship between oil price and allowance price, whereas Castagneto-Gissey (2013) found positive long-run relationships between gas price, oil price, electricity price and allowance price.

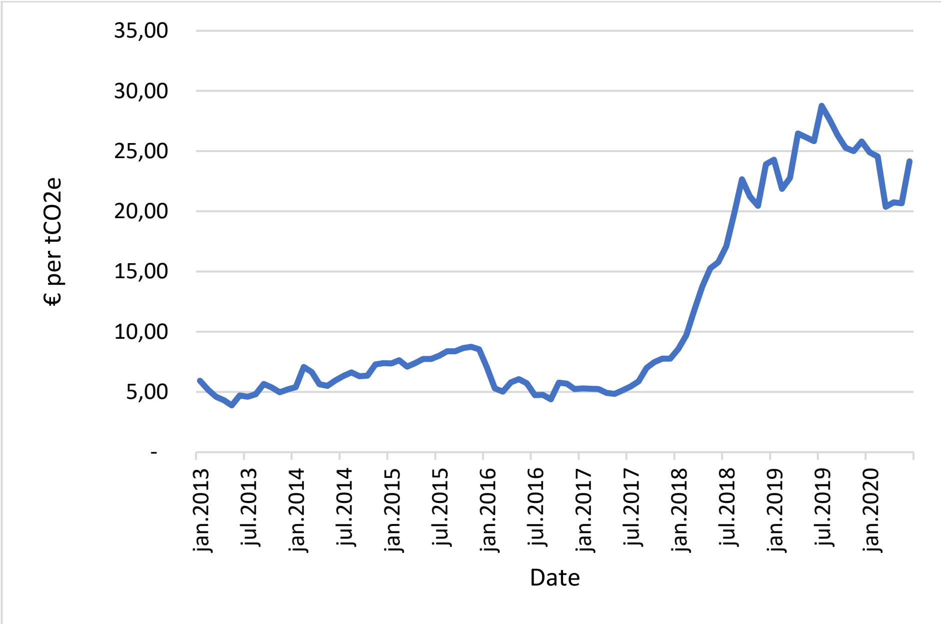
Moreover, several studies already decided to use longer time periods of the data in their analyses. Two of such were the studies by Creti, Jouvet and Mignon (2012) and Hammoudeh, Khuong Nguyen and M. Sousa (2014). First study opted for dynamic ordinary least square (DOLS) approach with cointegration and the second for the Bayesian structural vector autoregression model (BSVAR). With regard to variables used, both studies included variables that were already frequently used in this area of research, namely allowance price, fossil fuel prices, electricity price and stock index. Creti, Jouvet and Mignon (2012) found that during Phase II, a positive long-run relationship existed between Euro Stoxx 50 index, oil price, switch price and the allowance price. Hammoudeh, Khuong Nguyen and M. Sousa (2014) found that in the short-run with imposition of positive shocks to oil price, resulted in firstly positive but later negative effect on allowance price. A positive shock to coal price resulted in positive impact on allowance price. On the other hand, positive shock to electricity price and gas price both impacted the allowance price in a negative manner.

3.3 Phase III

Building upon the Phase II categories of allowance price drivers, studies of Phase III provide additional explanatory variables in this research topic, corresponding to economic category of variables. Variables, representing economic category, are industrial production index and bank lending index.

Furthermore, it should be noted that studies on the topic of allowance price formation for the whole period of Phase III will be available only after the start of the subsequent Phase. However, last year of Phase III presents with specificities that can require the utilization of different approaches and alter modelling of price determinants of the allowance price. Nevertheless, these specificities are discussed in this subchapter but are not included in my empirical analysis.

Figure 9: EU ETS allowance price movement for futures in Phase III in € per tCO2e (January 2013 – June 2020)



Source: Own work based on data from ICE (2020).

Figure 9 presents the movement of the futures allowance price in Phase III up to June 2020. The first 4 years of the Phase were a continuation of depressed allowance prices at about €5 with a small increase towards the end of 2015. Around mid-2017, the allowance price started to increase and reached its peak (so far) at almost €30 in mid-2019. Afterwards, the price declined but persists within a range of €20 to €25. A sharp decline in the beginning of February 2020 may be due to the news of the UK restarting allowance auctioning in March 2020 after the suspension of auctioning was lifted by the European Commission in the early February 2020. The UK was suspended from any allowance auctioning since January 2019 due to the uncertainty regarding the UK's withdrawal from the EU back in 2018 (Watson, 2020). With regard to Brexit, it is still premature to make any conlusions whether it made more or less significant impact on allowance prices in EU ETS. Furthermore, global situation due to the COVID-19 pandemic affected the EU ETS, primarily the allowance price. Lockdown measures across the EU negatively impacted aviation and many other economic activites. This resulted in considerably lower demand for allowances and subsequently, lowering the allowance price. Additionally, due to the global dimension of the COVID-19 crisis, markets across the globe plunged, which led numerous speculative investors to exit carbon market. The latter provided with additional, downward pressure on carbon price (Hatherick, 2020).

A study that focuses entirely on Phase III of the EU ETS is the study by Chung, Jeong and Young (2018). This study used data from 2013 to 2017 but is still one of the most recent studies that used the latest data available of Phase III for the allowance pricing purposes. To explain the allowance price formation, authors used similar variables as Koch, Fuss, Grosjean and Edenhofer (2014) for Phase II in the previous subchapter. However, this particular study also incorporated variables such as the industrial production index and bank lending index for economic variables and precipitation index for variables linked to weather conditions. Similarly to Koch, Fuss, Grosjean and Edenhofer (2014) study for Phase II, this study also utilizes data with monthly frequency and futures prices. Conversely to the studies by Alberola, Chevallier and Chèze (2008) and Koch, Fuss, Grosjean and Edenhofer (2014), Chung, Jeong and Young (2018) study opted for a VECM instead of a standard OLS approach. Additionally, study by Uludağ (2019) opted for the autoregressive distributed lag model (ARDL) model due to the inclusion of structural breaks in the analysis and used the longest time period of data, namely from the beginning of Phase II until December 2017 inclusively. In the long-run, Uludağ (2019) found positive impact of coal price and industrial production index on allowance price but negative effect of gas price.

4 EMPIRICAL ANALYSIS

This chapter contains the empirical analysis conducted to provide an insight into the creation of the EU ETS allowance price. In this regard, I take into account all variables that have been used in similar past studies, such as fossil fuels, weather and economic variables. The value-added of this research comes from the inclusion of exchange rate as a new variable that has not been used in previous literature in the topics of long-term relationships of allowance price drivers in the EU ETS. Specifically, I look for a possible effect of USD/EUR, GBP/EUR, and CNY/EUR exchange rates on the allowance price. Firstly, I describe and summarize raw data. Secondly, I depict the overall methodology. The importance is given to the notion of the overall methodology because two main models can be used for identifying long-run interactions. Additionally, methodology also describes the basic procedures undertaken in thesis. I then further depict the econometric model used in this analysis. Lastly, I provide the results of my analysis and respective diagnostic tests. An interpretation of the results is included accordingly.

4.1 Data description

In addition to EU ETS allowance prices, which were already described in-depth in the previous chapters, data description includes the main explanatory variables – fossil fuels, weather-condition variables and macroeconomic variables together, including exchange rates. Lastly, potential dummy variables are introduced. It should be noted that EU ETS allowance prices are based on futures contract prices instead of spot prices, taking into account that spot prices are more volatile than their futures counterparts (Trück, Härdle, & Weron, 2012).

Table 1: Variables

Variable categories	**Variable**	**Variable description**	**Data source**
Price	EUA	European Union Allowance Futures	InterContinental Exchange
Economic	IPI	Industrial Production Index	Eurostat
	ESI	Economic Sentiment Indicator	Eurostat
	USD/EUR	Exchange rate	ECB Statistical Data Warehouse
	GBP/EUR	Exchange rate	ECB Statistical Data Warehouse
	CNY/EUR	Exchange rate	Investing.com
Energy	Coal	API2 Rotterdam Coal Futures	InterContinental Exchange
	Natural gas	UK Natural Gas Futures	InterContinental Exchange
	Brent oil	Brent Crude Futures	InterContinental Exchange
	Electricity	Belgian Power Futures	InterContinental Exchange
Weather	HDD	Heating Degree Days Index	Eurostat

Source: Own work.

Table 1 presents the list of variables used in the modelling exercise. The variables taken into account are the allowance prices (EUA), fossil fuel prices (comprised of coal, natural gas and brent oil prices), electricity prices, heating-degree days index (HDD), industrial production index (IPI), economic sentiment index (ESI) and the exchange rates of USD/EUR, GBP/EUR, CNY/EUR.

My research includes variables measured on a monthly basis, spanning from July 2006 to December 2019. Monthly-obtained data is appropriate for the analysis due to the availability of relatively high-frequency data. In comparison to daily data, monthly data is preferred due to potential distortions in variables as a consequence of possible low daily trading volumes (Oberndorfer, 2009). The reason for including variables only since July 2006 onward is due to data availability of the coal variable. The reason for including variables up until the beginning of 2020 is twofold. Firstly, the heating-degree days (HDD) variable data is not available after the beginning of 2020. Secondly, the global COVID-19 pandemic and its related effects on the global economy, could hinder the modelling aspect of this analysis, if data from 2020 were included.

The EU ETS allowance prices are acquired from the InterContinental Exchange (ICE) in monthly frequency. The futures prices of one EUA are quoted in Euro per metric tonne of CO2e and the unit of trading is given in lots. One lot of EU ETS allowance price consists of 1.000 carbon emission allowances. Despite the carbon-linked name, the same measuring principle is used for gases equivalent to carbon dioxide (ICE, n/a).

The first group of explanatory variables in the energy category are fossil fuel prices. Various studies observe relationships between carbon and energy markets. Mansanet-Bataller, Pardo and Valor (2007) provided one of the first analyses on price determinats of the EU ETS allowance price and proved that natural gas and and brent oil price changes are one of the most important drivers of EU ETS allowance price change. In addition, Alberola, Chevallier and Chèze (2008), Hammoudeh, Khuong Nguyen and M. Sousa (2014) also included oil, natural gas and coal prices, whereas Hintermann (2010) and Koch, Fuss, Grosjean and

Edenhofer (2014) coal and natural gas prices among other variables. This shows that fossil fuel prices are commonly included as explanatory variables in analyses concerning price determination of EU ETS allowance price. Since data for oil, coal and natural gas were quoted in USD and GBP currencies, they were converted into EUR before entering the model. All conversions were made with monthly average exchange rates.

An additional variable in the energy category that is distinct from fossil fuel prices but is closely linked with them is electricity. The link between electricity and fossil fuels comes from fossil fuels driving power plants for electricity production. Based on Eurostat statistics (2020a), electricity production in the EU is divided between various sources. In 2019, almost 43% of electricity came from conventional thermal sources (mostly fossil fuels), almost 27% came from nuclear power plants, more than 13% came from wind energy and over 12% came from hydro energy. The remaining percentages are divided between solar, geothermal and other energy sources. It should be noted that electricity production by source differs across the EU Member States. Similarly to fossil fuel prices, electricity price is found in numerous studies which look for allowance price determinants within EU ETS.

Variables in the economic category are also frequently used in studies about price determination of the EU ETS allowances. The rationale for using this category of variables in such analyses stems from the fact that economic endeavor impacts carbon prices. The impact is transmitted through various channels. This impact can be depicted with an example, assuming growing economic activites. With increased economic growth, production processes will be encouraged and therefore electricity consumption will increase. Increased electricity consumption implies that the amount of fossil fuels needed for electricity production will increase and more gases will be emitted. With increased emissions, the demand for EU ETS allowances will rise. In the context of this study, economic variables are represented by industrial production index (IPI) and economic sentiment indicator (ESI) as well as the exchange rates.

The IPI is an important indicator in recognizing critical junctures in economic development and estimating growth of the economy. Hence, its inclusion in this research is warranted. Similarly, ESI presents an outlook on the economy and its potential growth. This indicator stems from confidence indicators based on businesses and consumer surveys (Eurostat, n.d.). On the other hand, exchange rates are a rare occurrance in econometric modelling on the topic of EU ETS. The inclusion of exchange rates stems from a study by Su and Deng (2019), who obtained heterogeneous effects of exchange rate on emission allowance price in China. The exchange rates used in my analysis are the exchange rates of the euro against the currencies of the EU's largest trading partners. In 2019, these countries were the United States of America, China and the United Kingdom (European Commission, 2020a).

The fourth category of variables covers the weather conditions. Extreme weather conditions have proved to have an ambiguous impact on allowance price changes. Alberola, Chevallier and Chèze (2008) presented such results with the inclusion of extreme and, in essence unforseen, weather events that affected carbon prices significantly in one period but did not affect the carbon price in other studied periods. Abrupt variations in climate comprise of wind, rainfall and temperatures to name a few. The consequence of these events is reflected in hot summers and/or cold winters, which, in effect, rises the demand for cooling and/or heating. Subsequently, the demand for electricity also rises. Few of the studies, which include the weather condition variables are, among others, Mansanet-Bataller, Pardo and Valor (2007), Alberola, Chevallier and Chèze (2008), Hintermann (2010), Chung, Jeong and Young (2018) and Uludağ (2019).

Additionally, certain weather variables such as hours of sunshine and wind flow speed also impact “greener” power generation production. Renewable energy supply mostly comprises of solar, wind and hydropower energy and does not emit carbon but relies heavily on the weather conditions. Therefore, the weather-related variables are broadly recognised in analyses of carbon pricing (Chevallier, 2012).

With regard to this analysis, a readily available weather variable is the heating-degree day index (HDD), reported by Eurostat. This specific index characterizes the need for heating, considering average room and outdoor temperature in a particular time period in a particular environment. The time period and the environment pose as two factors in determining the base temperature, which is fixed at 15°C and presents fundamentally the lowest daily mean air temperature without heating. In other words, if the daily mean air temperature is below 15°C, the HDD index for that particular day accounts for the temperature difference between 18°C and the actual mean daily air temperature. In the case when the daily mean air temperature is 15°C or more, there is no need for heating and the HDD index is 0. This index is estimated on the basis of temperature observations of around 3000 weather stations across Europe (Eurostat, 2020b). It should be further noted that buildings account for about 40% of total energy consumption in the EU. Additionally, they are responsible for approximately 36% of CO2 emissions. From a different point of view, around 35% of buildings in the EU are at least 50 years old and about 75% of buildings are energy inefficient (European Commission, 2019).

In addition to the already mentioned variables, I also use dummy variables to take into account for possible structural breaks in given time series. For this reason, a multiple breakpoint test is applied. The identified structural break corresponds to policy changes.

This analysis consists of an overall 162 observations for each variable, beginning in July 2006 and ending in December 2019. The period considered covers almost half of Phase I, Phase II and 7 years of the 8-year long Phase III of the EU ETS.

Table 2: Descriptive statistics of the raw data

	Unit	N	Mean	Median	Max	Min	Std.Dev.	Skewness	Kurtosis
EUA	€/tCO2e	162	12.279	9.351	29.69	3.886	6.91	.814	2.606
USDEUR	$/€	162	1.273	1.29	1.577	1.054	.13	.126	2.154
GBPEUR	£/€	162	.821	.844	.92	.663	.07	-.825	2.583
CNYEUR	CN¥/€	162	8.529	8.198	11.061	6.653	1.131	.595	2.267
COAL	$/t of coal	162	87.43	85.237	164.297	38.164	24.093	.311	2.666
GAS	£/therm*	162	53.343	50.82	92.652	28.751	12.157	.578	3.281
BRENT	$/barrel	162	78.857	74.408	136.655	37.125	22.811	.329	1.965
ELEC	€/MWh	162	49.04	47.899	93.515	27.857	11.438	1.331	6.105
IPI	/	162	100.226	100.25	108.8	86	5.254	-.473	2.638
ESI	/	162	99.54	102.05	114.7	65.2	10.755	-1.099	4.01
HDD	˚C	162	251.128	235.48	637.25	8.18	183.243	.239	1.696

*1 therm equals 29.3071 kilowatt hours

Source: Own work.

The descriptive statistics of raw data, presented in Table 2, is comprised of units of each variable, number of observations, mean, median, maximum, minimum, standard deviation, skewness and kurtosis. EUA prices vary between €3.886 and €29.69 in the studied period. Distribution of EUA prices is right-skewed and platykurtic. The exchange rates are the most stable variables among all variables. In particular, GBP/EUR is the most stable variable and the only exchange rate with a left-skewed distribution. On the other hand, USD/EUR and CNY/EUR are both right-skewed. In the studied period, GBP/EUR varied between £/€0.663 and £/€0.92, whereas USD/EUR varied between $/€1.054 and $/€1.577 and CNY/EUR between CN¥/€6.653 and CN¥/€1.061. All three exchange rates are platykurtic. All energy variables (coal prices, natural gas prices, brent oil prices and electricity prices) are also positively skewed. Among all variables, electricity price has the most right-skewed distribution and the most prominent leptokurtic distribution. In the period considered, electricity prices vary between €27.857 and €93.515. Distribution of gas prices is also leptokurtic and vary between £28.751 and £92.652 in the studied period. Coal and oil prices show platykurtic distribution. Coal prices vary between $38.164 and $164.297, whereas oil prices vary between $37.125 and $136.655 in the period considered. Among negatively skewed distributions of GBP/EUR, IPI and ESI, distribution of variable ESI is the most left-skewed. In studied period, ESI varies between 65.2 and 114.7 and is leptokurtic. On the contrary, distribution of IPI is platykurtic, varying between 86 and 108.8 in the given period. The last and the most volatile variable is HDD, with temperature sums over the considered period varying between 8.18 ˚C and 637.25 ˚C. Among EUA prices, USD/EUR, CNY/EUR and energy prices, distribution of the HDD is the most positively skewed. In terms of kurtosis, its distribution is platykurtic.

Table 3: Normality tests with respective probabilities

	Unit	N	Shapiro Wilk	SK joint prob.	Jarque Bera
EUA	€/tCO2e	162	0.000	0.001	0.000
USDEUR	$/€	162	0.000	0.003	0.077
GBPEUR	£/€	162	0.000	0.001	0.000
CNYEUR	CN¥/€	162	0.000	0.001	0.001
COAL	$/t of coal	162	0.051	0.180	0.193
GAS	£/therm	162	0.001	0.014	0.007
BRENT	$/barrel	162	0.000	0.000	0.006
ELEC	€/MWh	162	0.000	0.000	0.000
IPI	/	162	0.000	0.039	0.031
ESI	/	162	0.000	0.000	0.000
HDD	˚C	162	0.000	0.000	0.001

Source: Own work.

The normality of data distribution is further examined in Table 3 with three different tests for normality. The tests presented in this table are used to firmly conclude on non-normality of given data distribution. The tests consist of Shapiro-Wilk test, SK joint test and Jarque-Bera test. The only variable that can be depicted as normaly distributed is coal, whereas with all other variables, the null hypothesis of normally distributed data is rejected.

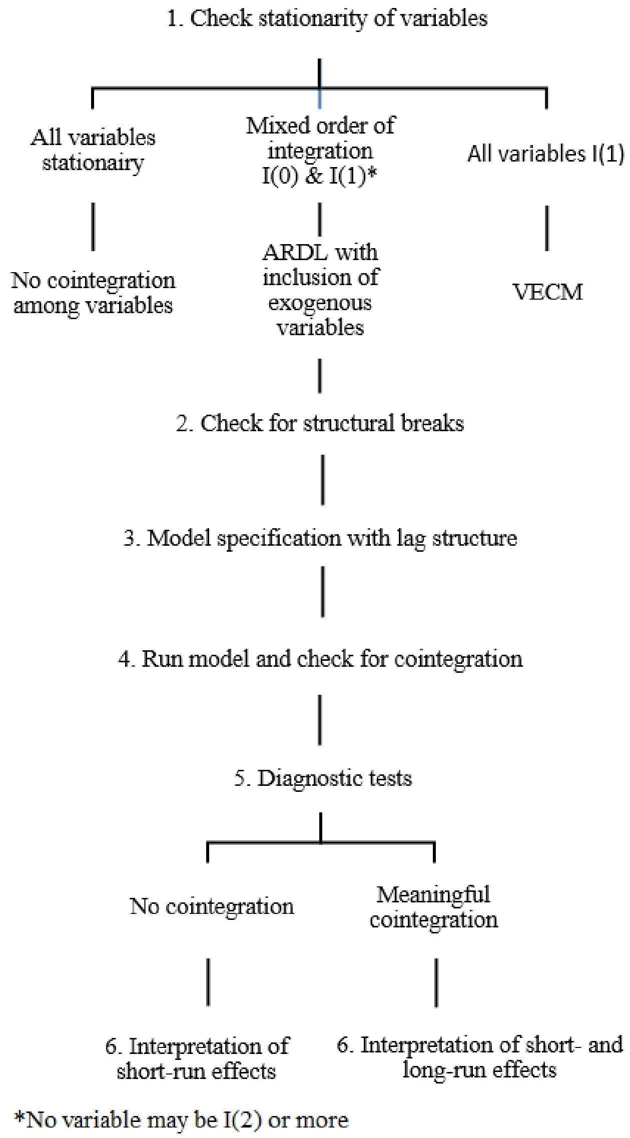
Due to the non-normal distribution of almost all variables presented in Table 3, I applied natural logarithms to the selected variables. With this transformation, I achieve greater homogeneity of the variance and stronger model stability. The latter is presented in the subchapter results.

4.2 Methodology

My objective is to identify both short-run and long-run relationships among the presented variables. The main models to be considered for identification of long-run relationships in such cases are the VECM and the autoregressive distributed lag (ARDL) model. A few studies that dealt with cointegrating relationships in the context of the EU ETS are Nazifi and Milunovich (2010), Peri and Baldi (2011), Creti, Jouvet and Mignon (2012), Castagneto-Gissey (2013), Chung, Jeong and Young (2018) and Uludağ (2019).

Methodology employed for my research consists of several necessary steps in order to make a meaningful and correct interpretation of the results. Furthermore, taking all the required steps in econometric analysis enables easier decision-making about model choice and suitability of the chosen model for the purposes of one's research.

Figure 10: Sequence of steps



Source: Own work.

Figure 10 illustrates the procedure of the modelling exercise. Regardless of the chosen model (VECM or ARDL), stationarity of time series needs to be ensured. For this reason, I conduct augmented Dickey-Fuller (ADF) test with the null hypothesis that individual variable contains a unit root and is therefore non-stationary (Stock & Watson, 2015). The ADF test is also useful in determining the order of integration of variables. This is an important step in the analysis to choose the right dynamic model for the selected time series.

After determining the order of integration of the variables, I conduct the analysis with the chosen model. When identifying cointegration relationships between variables the model of choice can either be the VECM or ARDL. The former model can only be applied when all of the variables are I(1), whereas the ARDL model can also be applied in the case of variables with mixed orders of integration, namely I(0) and/or I(1). It should be emphasized that

ARDL model can also be applied for variables that are only I(1) (Pesaran & Shin, 1999). Furthermore, conventional VECM model cannot accommodate for exogenous variables (Pesaran, Shin, & Smith, 2000) (e.g. dummies). The ARDL model therefore provides more flexibility in terms of selected variables and with allowing for exogenous variables such as dummies, because the analysis of time series can include potential structural breaks. In my analysis, weather condition variables can technically be treated as exogenous to the allowance price determination modelling. The reason behind this treatment is due to the fact that values of weather condition variables are given outside the model, are not dependent on the states of other variables in the model and are not explained by the model (Fair, n.d.). They are simultaneously determined outside the model environment. However, studies by Nazifi and Milunovich (2010), Chung, Jeong and Young (2018) and Uludag (2019) use the temperature variables in their VECM and ARDL models, thus, treating them endogeneously. In my model specification, weather variable is also considered in the long-run equation to control for its result.

Due to the nature of this research and its novelty of including exchange rates, finding the appropriate model specification can be time-consuming, but also essential in order to make correct inferences. One of the diagnostic tests that most evidently illustrates the problem of model misspecification are the stability tests. Brown, Durbin & Evans (1975) proposed CUSUM and CUSUMSQ test based on recursive residuals. These two tests provide a plot rather than following a standard hypothesis testing procedure. However, the null hypothesis can be depicted as coefficient constancy. Both tests consist of confidence bands based on the significance level. The difference between the two tests stems from the fact that CUSUM uses the cumulative sum of recursive residuals, whereas CUSUMSQ uses the cumulative sum of squared recursive residuals. To include only stable variables, the plot must not surpass the confidence lines (Brown, Durbin, & Evans, 1975). If the plot surpasses the confidence lines, the reasons for model instability can be multifold: structural breaks, omission of relevant variable(s), or general model misspecification. Stability diagnostics with respect to the determination of structural breaks in my analysis are perfomed in statistical package Eviews because the version of STATA used for this analysis is older and does not offer convenient commands for identifying structural breaks.

In my analysis, I also apply diagnostic tests for autocorrelation and heteroscedasticity. The Breusch-Godfrey test, which is a Lagrange multiplier (LM) test, is carried out to test for the presence of autocorrelation. The null hypothesis in this case is that there is no autocorrelation present in the time series. If the null hypothesis is rejected, the alternative hypothesis of a certain degree of autocorrelation between the current and lagged residuals is accepted. The Breusch-Pagan LM test is carried out to test for the presence of heteroscedasticity. The null hypothesis in this test assumes that the variances of disturbances are homoscedastic. In the case the null hypothesis is rejected, variances of these disturbances vary across the regression line and are therefore heteroscedastic (Greene, 2002).

After the model is specified and the diagnostic tests show no autocorrelation, heteroscedasticity and no substantial instability of the model, interpretations of the short- and long-run relationships follow. To discover whether there is cointegration between variables and therefore an interpretation of a long-run relationship is warranted, the appropriate test for cointegration is used. The most common tests in this matter are the bounds test and the Johansen test. The decision which one is used depends on the chosen model.

Because my intent is to identifiy short- and long-run effects of selected variables in modelling the EU ETS allowance price in the period between June 2006 and December 2019, I choose to apply the autoregressive distributed lag (ARDL) model. Reasoning for the use of this particular model is provided in subsequent chapter. Since cointegration is one of the highlights this model has to offer, one of the earliest papers in this topic of research was done by Pesaran and Shin (1999) on variables that were exclusively I(1). Later, Pesaran, Shin and Smith (2001) also presented cointegration approaches to the analysis of relationships in levels (i.e. I(0) variables).

However, before tapping into the cointegration aspect of the model, its basic requirements have to be met. Time series particularity lies in the assumptions of stationarity of the underlying variables. By having first and second moments varying in time, multiple problems can occur. Among others, statistical inferences for typical OLS approaches can be inaccurate, forecasts can be inefficient as well as biased. Practice has uncovered that time series used for the purposes of economic analyses usually violate the assumption of stationarity. It is also necessary to identify whether the ARDL model is appropriate for a given time series by testing the order of integration of the variables, which signifies the number of how many times the variable needs to be differenced in order to become stationary (Stock & Watson, 2015). In contrast to the VECM that is also used for identifying long-run effects, it can only accommodate for variables that are I(1), whereas ARDL can also be applied in the case of variables that are I(1) and/or I(0). ARDL, however, cannot be used in case of an included variable that is I(2) (Pesaran, Shin & Smith, 2001).

Additional advantages of this model are found in the fact that it accommodates for different lag lengths of the variables in the model and that it consists of a single equation setup. The latter is helpful as the inferences of the regression are simple to convey. The most general form of an ARDL model consists of p lags of the regressand and q lags of regressor(s).

The elementary form of an ARDL (p, q) model can be portrayed as:

$$y_t = \beta_0 + \beta_1 y_{t-1} + \ldots + \beta_p y_{t-p} + \alpha_0 x_t + \alpha_1 x_{t-1} + \ldots + \alpha_q x_{t-q} + \varepsilon_t \qquad (1)$$

where y_t is the dependent variable, β_0 the intercept, β and α the unknown coefficients, x_t the independent variable(s) and ε_t is the error term that is serially independent. However, for identifying long-run relationships, the model itself has to be reparameterized into an error correction model (ECM):

$$\Delta y_t = \beta_0 + \Sigma_{i=1}^{p}\beta_i \Delta y_{t-i} + \Sigma_{i=1}^{q}\gamma_i \Delta(x_1)_{t-i} + \Sigma_{i=1}^{q}\delta_i \Delta(x_2)_{t-i} + \cdots + \Sigma_{i=1}^{q}\vartheta_i \Delta(x_n)_{t-i} + \theta_1 y_{t-1} + \theta_2 (x_1)_{t-1} + \theta_3 (x_2)_{t-1} + \cdots + \theta_m (x_n)_{t-1} + \varepsilon_t \qquad (2)$$

where Δ represents the difference operator. Equation (2) also allows for cointegration testing. The null hypothesis is represented by having $\theta_1 = \theta_2 = \theta_3 = \ldots = \theta_m = 0$. If existence of cointegration relation is detected, the null hypothesis is rejected.

Moreover, ARDL model consists of variables that are I(0) and/or I(1), thus, an appropriate test for cointegration is the so-called bounds test. Pesaran, Shin and Smith (2001) propose a procedure in which the null hypothesis of cointegration is applied to the conditional ECM. The authors provided tables of critical value bounds for asymptotic distribution of F-statistics. The interpretation of results of bounds testing depends on F- and t-statistics and come in three possible outcomes. Firstly, if F- and t-statistics fall above the thresholds for I(0) and I(1) variables, there is a conclusive inference of cointegration. If the statistics are below the thresholds, then there is a conclusive inference of no cointegration between the variables. The last possible outcome is inconclusive inference with statistics falling in-between the bounds. The importance of this particular cointegration test is that the underlying variables can be I(0) and/or I(1), whereas multiple cointegration tests exist but only for cases of underlying variables that are exclusively I(1). Some of these tests are Johansen's test of cointegration (1991) and Shin's residual-based test of the null of cointegration (1994).

4.3 Results

Following the description of methodology used in my study, this section reports explanation of the results of the analysis. I begin with interpreting results of the unit root tests. Then, test for identifying structural breaks is conducted. I continue with model specification and conduct bounds test for identifying the possible cointegration. Before interpreting the results of the bounds test, I apply tests for autocorrelation, heteroscedasticity and CUSUM tests. Following diagnostic tests, I interpret the results of bounds test and respective short- and long-run relationships. Moreover, I also provide comparison of my results to results of other studies.

Table 4: Augmented Dickey-Fuller test of unit root for specified variables

AUGMENTED DICKEY-FULLER TEST OF UNIT ROOT											
At level											
	LEUA	LUSDEUR	LGBPEUR	LCNYEUR	LCOALE	LGASE	LBRENTE	LELEC	LIPI	LESI	LHDD
t-statistics	-0.951	-1.065	-2.073	-1.681	-2.617	-1.876	-1.850	-1.955	-1.202	-1.202	-4.416
P-value	0.7707	0.7288	0.2557	0.4410	0.0895	0.3435	0.3557	0.3069	0.6725	0.6728	0.0003
Stationarity	No	No	No	No	No	No	No	No	No	No	***
At first difference											
	dEUA	dUSDEUR	dGBPEUR	dCNYEUR	dCOALE	dGASE	dBRENTE	dELEC	dIPI	dESI	dHDD
t-statistics	-8.181	-9.442	-10.305	-13.576	-12.217	-8.413	-9.294	-7.781	-10.803	-5.544	-6.949
P-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Stationarity	***	***	***	***	***	***	***	***	***	***	***

Based on MacKinnon (1996) one sided p-values: (***) Significant at 1%
(No) Not significant

Source: Own work based on data from ICE (2020).

Table 4 presents Augmented Dickey-Fuller test of unit root for specified variables. As can be observed, only the natural logarithm of the heating-degree day index (LHDD) is stationary at level, whereas all other variables become stationary in first differences. This implies that my chosen variables are of mixed order of integration, namely I(0) and I(1), which further supports the use of the ARDL model for the given time series. If all variables were I(1), the model of choice may become VECM. However, variables included in my model specification also consists of exogenous variables, therefore I can only use the ARDL model.

Starting with the process of determining the appropriate model specification, all variables are initially included in the model. Subsequently, variables are excluded from the model based on their insignificance and their contribution to model instability. On this basis, I excluded the natural logarithm of industrial production index (LIPI), economic sentiment indicator (LESI) and and the GBP/EUR exchange rate (LGBPEUR) from model specification.

Table 5: Multiple breakpoint tests for identifiying structural breaks of time series

No. of breaks	Estimated break dates					Schwarz criterion	LWZ criterion
0	/						
1	2011M08						
2	2009M03	2015M12					
3	2008M07	2011M08	2015M12				
4	2008M07	2011M01	2013M01	2018M01			x
5	2008M07	2011M01	2013M01	2016M01	2018M01	x	

Source: Own work based on data from ICE (2020).

Table 5 shows the number and time period of identified structural breaks. Despite the number of breaks identified based on Schwarz and LWZ criterion (5 and 4, respectively), only 1 structural break entered the model. The reason behind this is that most of the estimated breaks add to model instability. Structural break that entered the model is January 2018. The first estimated break, occurring in July 2008 reflects the effects of the global economic downturn as well as the European Commission's Amendment to the Directive on the inclusion of aviation in the EU ETS that was agreed upon. The break in January 2013 can be attributed to European debt crisis and its effects (Uludağ, 2019). Furthermore, this break can be considered as a break that accommodates the transition between Phase II to Phase III of the EU ETS, in particular, with the abolition of national caps as described in in second chapter of this thesis. Finally, the break in January 2018 is deemed to reflect the adoption of the revised EU ETS Directive 2018/410, which was also presented in the second chapter of the thesis. Based on the aforementioned Directive, the adoption process for the inclusion of emissions from international shipping into the EU ETS started. In another aspect, the amount of emissions from stationary establishments increased by 0.25% in 2017 compared to 2016. Despite overwhelming level of compliance to the EU ETS rules, about 1% of stationary establishments did not submit allowances that would cover all their emissions from 2017 by the deadline in the spring of 2018 (European Commission, n.d.i).

Moreover, STATA as a statistical package provides a helpful command option by which it is not necessary to determine the optimal lag structure separately before the model is run. By adding the *aic* after the *ardl* command and the underlying variables, STATA runs the model and simultaneously applies the optimal lag length to the variables. The chosen method of specifying the optimal lag length of the variables is based on the Akaike Information Criteria (AIC).

The selected model specification in this analysis is ARDL (3,0,1,1,4,0,4,0), based on AIC criterion. The specified lag structure entails the use of 3 lags for LEUA, 0 lags for LUSDEUR, 1 lag for LCNYEUR, 1 lag for LCOALE, 4 lags for LGASE, 0 lags for LBRENTE and 4 lags for LELEC and 0 lags for LHDD. Thus, the model can be specified in a different notation:

$$\begin{aligned}\Delta LEUA_t = \ & \beta_0 + \Sigma_{i=1}^{p}\beta_i \Delta LEUA_{t-i} + \Sigma_{i=1}^{q}\gamma_i \Delta(LUSDEUR)_{t-i} + \\ & \Sigma_{i=1}^{q}\delta_i \Delta(\mathrm{LCNYEUR})_{t-i} + \Sigma_{i=1}^{q}\vartheta_i \Delta(\mathrm{LCOALE})_{t-i} + \Sigma_{i=1}^{q}\mu_i \Delta(\mathrm{LGASE})_{t-i} + \\ & \Sigma_{i=1}^{q}\pi_i \Delta(\mathrm{LBRENTE})_{t-i} + \Sigma_{i=1}^{q}\rho_i \Delta(\mathrm{LELEC})_{t-i} + \Sigma_{i=1}^{q}\sigma_i \Delta(\mathrm{LHDD})_{t-i} + \theta_1 LEUA_{t-1} + \\ & \theta_2(\mathrm{LUSDEUR})_{t-1} + \theta_3(\mathrm{LCNYEUR})_{t-1} + \theta_3(\mathrm{LCOALE})_{t-1} + \theta_3(\mathrm{LGASE})_{t-1} + \\ & \theta_3(\mathrm{LBRENTE})_{t-1} + \theta_3(\mathrm{LELEC})_{t-1} + \theta_3(\mathrm{LHDD})_{t-1} + \tau \mathrm{dum2018m1} \qquad (3)\end{aligned}$$

Table 6: Results of bounds test for cointegration

	F-statistics	5.080	t-statistics	-5.175
Critical values	Lower bound I(0)	Upper bound I(1)	Lower bound I(0)	Upper bound I(1)
1%	2.873	4.320	-3.441	-5.378
5%	2.244	3.519	-2.829	-4.688
10%	1.953	3.140	-2.516	-4.324
p-value	0.000	0.002	0.000	0.017

Source: Own work based on data from ICE (2020).

After estimating the model regression, the bounds test can be performed. As shown in Table 6, the results of the bounds test for cointegration with its F- and t-statistics are conclusive. I reject the null hypothesis of no cointegration because the F-statistics with the value of 5.080 is higher than the critical value bounds of I(0) and I(1) at 1% significance level. Thus, I conclude that cointegration among the variables exist. P-values and t-statistics also confirm the latter conclusion, albeit at 5% significance level.

However, before interpreting the regression results, further diagnostics tests are made to avoid possible misleading conclusions. First, I test for the presence of autocorrelation in the model and second, I also test for the presence of heteroscedasticity. Last, CUSUM and CUSUMSQ diagnostics tests are presented to show if the model is potentially unstable.

Table 7: Results of tests for autocorrelation and heteroscedasticity

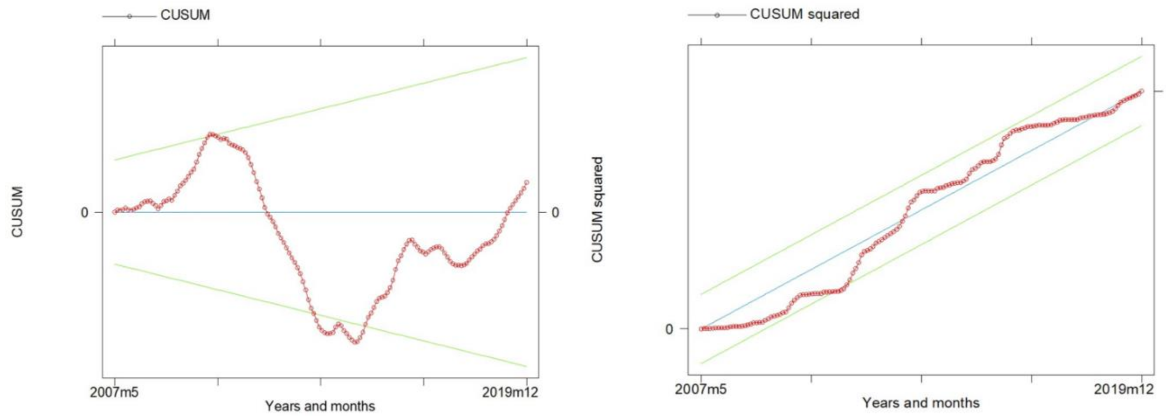
Test	Null hypothesis	p-value
Breusch-Godfrey LM test	No autocorrelation	0.3622
Breusch-Pagan test	No heteroscedasticity	0.9008

Source: Own work based on data from ICE (2020).

Table 7 presents the results of the Breusch-Godfrey LM test for autocorrelation, which indicates a high p-value, implying that the null hypothesis of no serial correlation cannot be rejected. This leads me to conclude that autocorrelation is not present in the model. Additionally, Table 7 presents the results of the Breusch-Pagan test for the presence of heteroscedasticity in the model. A high p-value, standing at 0.9008, implies that the null hypothesis of constant variance cannot be rejected and therefore provides a proof that the variance of disturbances throughout the observations does not change. Thus, the conclusion of no heteroscedasticity in the model is made.

The last two of the diagnostic tests are the stability tests – CUSUM and CUSUMSQ test. Both tests consist of plots in which model specifications are tested for stability. The model is deemed stable if it stays within the 5% significance levels, presented with two lines in each test. If the model deviates from the significance levels, it does not stay within the two lines and the model is deemed instable. By observing and therefore concluding of model stability through CUSUM tests, it implies that there are no structural breaks that are not already included in the model through dummy variables.

Figure 11: CUSUM and CUSUMSQ tests for model stability



Source: Own work based on data from ICE (2020).

Figure 11 presents the results of both CUSUM tests. In both tests, the model performs well deviating only slightly outside the 5% significance levels, represented by the upper and lower lines in each graph. This may indicate the need to include additional structural breaks in the model. However, the inclusion of another identified break date(s) only further destabilizes the model.

After ensuring the validity of the model with the above described tests, I can now proceed to model interpretation. Since the bounds test provides conclusive and meaningful inference with regard to the long-run relationship among variables (conclusive presence of cointegration), I can interpret both the short- and long-run ARDL model with the ECM reparameterization. The notion of cointegration among the variables, further implies equilibrium for the economy, therefore, short-term price volatilities do not affect the variables. In my analysis, accordingly to the cointegration, statistically significant variables in the long-run are the exchange rates LUSDEUR and LCNYEUR, energy prices - LGASE and LELEC. On the contrary, LCOALE, LBRENTE and LHDD are not statistically significant in the long-run. Before the comprehensive intrerpretation of the long-run effects, I firstly interpret the short-run effects of the model.

Table 8: Model fit and short-run coefficients of the ARDL model

Panel A: Model fit				
R^2				0.5542
Adjusted R^2				0.4853
Root MSE				0.0808
Number of observations				158
Panel B: Short-run estimation				
Variable	Coefficient	Std. Err.	T-statistic	P-value
ECM(-1)	-.1491796	0.0288295	-5.17	0.000
c	1.630535	.4640187	3.51	0.001
ΔLEUA (-1)	.1866933	.0763362	2.45	0.016
ΔLEUA (-2)	-.1333104	.0769187	-1.73	0.085
ΔLCNYEUR	0.899637	0.2854888	3.15	0.002
ΔLCOALE	-.130759	0.0851481	-1.54	0.127
ΔLGASE	.5598626	.1763522	3.17	0.002
ΔLGASE (-1)	.3105747	.1662179	1.87	0.064
ΔLGASE (-2)	.4871776	.1730895	2.81	0.006
ΔLGASE (-3)	.5151518	.1738213	2.96	0.004
ΔLELEC	.4958812	.1971528	2.25	0.013
ΔLELEC (-1)	-.488345	.1963167	-2.49	0.014
ΔLELEC (-2)	-.0961463	.1951255	-0.49	0.623
ΔLELEC (-3)	-.3257295	.1722338	-1.89	0.061
dum2018m1	.0998868	.030126	3.32	0.001

Source: Own work based on data from ICE (2020).

Table 8 represents model fit in panel A and short-run coefficients of the ARDL model, namely the ECM regression results in panel B. The R^2 and adjusted R^2 of the specified model are appropriate and similar to the model fit in the study of Uludağ (2019) that applied same econometric approach in determination of EU ETS price drivers. The error correction term (ECM (-1)) represents the speed of adjustment, which is negative and statistically significant at 1% significance level. The speed of adjustment value is -0.149, which implies that, on average, 14.9% of the change in LEUA price level into disequilibrium is corrected within 1 period.

With regard to short-run coefficients, I firstly discuss the statistical significance of the selected variables. The change in two-month lagged value of LEUA, current value of LCOALE, one-month lagged LGASE and two- and three-month LELEC prices are statistically insignificant to explain the change in LEUA prices in the short-run. Furthermore, a study by Hammoudeh, Khuong Nguyen and M. Sousa (2014) suggests that in the absence of electricity prices, coal prices affect allowance prices in a positive manner. This finding entails the possibility of electricity price undertaking the effect of the coal prices on the allowance prices when both of the explanatory variables are present in the model. However, studies by Mansanet-Bataller, Pardo and Valor (2007) and Hintermann (2010) did not include electricity prices in their regressions, yet obtained no significant effect of coal prices on allownance prices. The result of coal prices not affecting the allowance prices in the short-run is consistent with the results of Mansanet-Bataller, Pardo and Valor (2007), Alberola, Chevallier and Chèze (2008) in subperiods, Hintermann (2010), Koch, Fuss, Grosjean and Edenhofer (2014) and Hammoudeh, Khuong Nguyen and M. Sousa (2014).

Although the aforementioned lags of LEUA, LGASE and LELEC prices do not have an effect on LEUA prices, one-month lagged LEUA, current, two- and three-month lags of LGASE and current and one-month lagged LELEC prices do have statistically significant effect on LEUA prices in the short-run. Additional variable that affects the LEUA prices in the short-run in a statistically significant manner is the exchange rate LCNYEUR. Furthermore, LEUA prices are affected by their one-month lagged value positively such that for every 1% increase in the one-month lagged LEUA price, the current LEUA price increases by almost 0.19% on average. This indicates that the current LEUA price captures the history of own price changes. This finding is compatible with studies by Hammoudeh, Khuong Nguyen and M. Sousa (2014) and Uludaḡ (2019). However, the increase in current LEUA price due to the effects of an increase of the one-month lagged LEUA price is counterintuitive at first look. The rationale is that a price increase may hurt the demand for the allowances in the consequent period. On the other hand, this finding can be explained by the fact that the EU ETS market works efficiently. If an establishment requires additional allowances that are scarce on the market, the EUA allowance price will increase in the consequent period. This is more evident from the observations in the second half of the Phase III.

Moreover, in the short-run, LEUA price is also affected by the exchange rate LCNYEUR. If the LCNYEUR increases by 1%, the LEUA price will, on average, rise by almost 0.9%. In other words, depreciation of CNY toward EUR currency (appreciation of EUR toward CNY currency) increases the allowance price. This is an expected result, since exchange rates (currencies pegged against EUR) are inevitably connected to the allowance price, quoted in EUR currency. The exchange rate itself stimulates EU–based companies to procure the goods in a country, which offers the lowest costs of goods. In an attempt to provide explanation on such result, I take into account international trade of goods. Import of goods from third countries entails that these goods and the corresponding emissions from the production of this goods are not under EU ETS jurisdiction. Furthermore, by procuring goods from third country, the demand in the EU for the same product decreases, which lowers the possibility of producing such goods in the EU, effectively decreasing the demand for EU ETS allowances. Moreover, changes to the production of goods take time and a negative relationship between LCNYEUR and allowance price, implied by a decrease in the demand for allowances, is therefore expected in the long-run.

Current and lagged values of LGASE prices affect the LEUA price positively in the short-run. A 1% increase in the current LGASE price results in an increase of the LEUA price by approximately 0.56% on average. Similarly, two- and three-month lagged values of LGASE prices affect the LEUA price by an increase of 0.49% and 0.52% on average in the short-run, respectively. This finding was expected and is in line with economic theory. If the gas prices rise, the gas-based productions will be stimulated to switch to cheaper, dirtier fuels (i.e. coal). This results in higher emissions and therefore, higher demand for allowances. With raised demand, the allowance prices rise accordingly. The positive relationship between LEUA price and LGASE price is also proved by Alberola, Chevallier and Chèze (2008), Hintermann (2010) and Koch, Fuss, Grosjean and Edenhofer (2014). On the other hand, an unexpected finding of this analysis is that in the short-run, only one-month lagged value of LGASE prices do not significantly influence the LEUA prices. However, this particular lag value did not result in strong insignificance at 0.064 p-value.

The short-run effect of the dummy variable representing EU ETS Directive 2018/410 on LEUA price was unexpected since the variable has been present only from 2018 onward and in its core not as far-reaching act as treaties or other EU decisions. Nevertheless, this dummy variable has proved to be an important part of the model specification already in identification of the structural breaks and thereby ensuring model stability. Since the time Directive 2018/410 entered force, its effect on the LEUA price results in an increase of an almost 0.1% on average in the short-run. The reason behind this finding stems from the fact that beside all the intended revisions for the Phase IV, Directive 2018/410 also includes maritime sector under the EU ETS. This sector accounted for 2.4% of global GHG emission in the period of 2007 – 2012. Moreover, projections of international shipping emissions showed a 50% to 250% of potential increase by the 2050 in case nothing is done to reduce these emissions (International Maritime Organization, 2015).

Lastly in the short-run coefficients of the ARDL model is the effect of current and one-month lagged LELEC prices on the LEUA price. The effect by each LELEC prices on the LEUA price is different. A 1% increase in the current LELEC price results in an approximately 0.5% increase in the LEUA price on average, whereas a 1% increase in one-month lagged LELEC price will, on average, decrease the LEUA price by approximately 0.49%. The first result is expected because regardless of the fossil fuel used in power generation, electricity price increases the allowance price (due to the demand for allowances). The second result is consistent with findings of Hammoudeh, Khuong Nguyen and M. Sousa (2014) that a positive shock to electricity price decreases allowance price and which effects are observed over a series of consequent months. The difference in the signs of coefficients of LELEC price might arise due to the power plants' inability to instantly switch from more expensive to cheaper fossil fuel. Thus, in a matter of few months, only the price of electricity can change in an upward motion. Furthermore, switching from one emission-generation technology to another, entails certain costs, which additionally drives the electricity price upwards.

Table 9: Long-run coefficients of the ARDL model

Variable	Coefficient	Std. Err.	T-statistic	p-value
Long-run estimation				
LUSDEUR	6.205504	1.663239	3.37	0.000
LCNYEUR	-5.618185	1.389982	-4.04	0.000
LCOALE	.3170836	.335869	0.94	0.347
LGASE	-2.473024	.7413004	-3.34	0.001
LBRENTE	-1.098636	.5743777	-1.91	0.058
LELEC	3.902579	.6801221	5.74	0.000
LHDD	.0448948	.0486011	0.92	0.357

Source: Own work based on data from ICE (2020).

Table 9 presents the long-run estimates of the ARDL model. In the long-run, variables that affect the LEUA price at 5% statistical significance level are the exchange rate LUSDEUR and LCNYEUR with different effects, LGASE price and LELEC price. LUSDEUR affects the LEUA prices positively in the long-run. A 1% increase in LUSDEUR leads to 6.2% increase in LEUA prices on average. On the other hand, a 1% increase in LCNYEUR results in 5.62% decrease in LEUA prices on average in the long-run. The rationale behind long-run relationship follows the logic of the short-run relationship between exchange rate and LEUA price. Peculiarity of these results is observed in different signs of the exchange rate coefficients in the long-run and could be attributed to the fact that USD is a free-floating currency, whereas CNY is not entirely free-floating. This implies that China is willing to defend its currency to be relatively low in value in order to stay competitive in the long-run and with it, still producing large quantities of export goods.

In regard to the natural gas, LGASE prices affect the LEUA prices negatively in the long – run. This stems from the fact that natural gas produces less emissions than coal or oil (U.S. Energy Information Administration, 2020). Therefore, a rise in demand for natural gas reduces the need of obtaining additional emission allowances. With 1% increase in LGASE prices, LEUA prices decrease by 2.47% on average in the long-run. This finding is further dissected by Bertrand (2013), who finds that a rise in the demand for natural gas in power-generation plants lowers the demand for the CO2, resulting in lower allowance prices. However, studies such as Alberola, Chevallier and Chèze (2008) and Hintermann (2010) show positive effect of natural gas prices toward allowance prices. On the other hand, my finding is also proved by Hammoudeh, Khuong Nguyen and M. Sousa (2014) and in the long-run by Chung, Jeong and Young (2018) and Uludağ (2019). The difference in signs of natural gas prices could stem from the inclusion of Phase II and III periods in the studies that resulted with a negative sign of this coefficient.

Furthermore, LELEC prices positively affect the LEUA prices in the long-run. If LELEC prices increase by 1%, LEUA prices surge by 3.9% on average. Studies by Nazifi and Milunovic (2010) and Castagneto-Gissey (2014) suggest that electricity price significantly affected the emission price during Phase I and Phase II, respectively. Both studies also proved that electricity price Granger causes the emission price. Nazifi and Milunovich (2010) found no long-run relationship between electricity price and allowance price, whereas Castagneto-Gissey (2014) found a positive long-run equilibrium between electricity price and allowance price, which is consistent with my results. The discrepancy in these results could be due to the inclusion of different time periods in the analyses, which might pertain the effects of more extreme weather observed in the recent Phases. A positive long-run relationship signifies that regardless of the fossil fuel used in power generation, an increase in electricity price results in surging of the allowance price. This supports the fact that less emission-generating technologies in energy production (i.e. hydro, solar, wind-based energy production) do not present a main share of power generation.

On the other hand, LCOALE, LBRENTE prices and LHDD index are statistically insignificant and thus, do not affect the LEUA price in the long-run. The LCOALE and LBRENTE prices were expected to be statistically insignificant to explain the LEUA price in the long-run. Firstly, LCOALE price was already statistically insignificant in the short-run and this result is also proved by multiple other studies as discussed in the short-run with the reasoning of the inclusion of electricity prices. Similar rationale is imposed in the case of LBRENTE price not affecting the LEUA price in the long-run. This is an expected result since Alberola, Chevallier and Chèze (2008) also found no such effect, despite the inclusion of electricity price. On the contrary, a study by Peri and Baldi (2011) found long-run relationship brent oil prices and the allowance prices. The discrepancy in results could be attributed to the use of spot brent oil prices, whereas my study and the study by Alberola, Chevallier and Chèze (2008) both used the futures brent oil prices. Furthermore, Peri and Baldi (2011) restricted their cointegration analysis to a shorter study period (from January 2008 until May 2009) and used only two variables - brent oil price and allowance price. Nevertheless, their finding coincides with the results of Creti, Jouvet and Mignon (2012), who also found long-run relationship between brent oil price and allowance price in Phase II but not in Phase I. Disparity between the findings could arise due to the worsened economic situation during Phase II of the EU ETS.

The LHDD index is statistically insignificant to explain long-run effects on the LEUA price. Despite the importance of the inclusion of weather and temperature conditions variables as argued by Alberola, Chevallier and Chèze (2008), Hintermann (2010) and Chevallier (2012), studies by Alberola, Chevallier and Chèze (2008) and Hintermann (2010), similarly to my findings, provide no statistically significant effects of extreme temperature and precipitation on allowance price. Moreover, a study by Uludağ (2019) applies the same ARDL approach and uses the same temperature variable as my study (LHDD index). Both studies coherently result in the LHDD index not affecting the allowance price in the long-run.

CONCLUSION

Climate change poses as the fundamental problem of our time. As a global phenomenon, its effects are observed in all countries around the world. These effects are shown as extreme weather conditions and events, which prove how vulnerable is our planet. With its countless negative consequences observed, the climate change in its scope, is unrivaled by any other natural phenomenom. Although GHG gases are found naturally occurring, it is the man-made intrusion in the nature that induced and continues to lead the catastrophical speed at which the climate change thrives. In this context, economic science attempts to address the negative externalities associated with climate change. Learning from small-scale examples and theories, penalising the polluter to reduce the emissions where it is least costly to do so, became the most flexible approach of efficient eradication of negative externalities. However, to pursue an overwhelming phenomenon such as climate change, international cooperation and negotiations were necessary. A common goal and framework for all the future Agreements was outlined by the UNFCCC in 1992. This was followed by the Kyoto Protocol, which introduced three mechanisms – emission trading, Clean Development Mechanism and Joint Implementation. Despite extensive novelties of the Kyoto Protocol, the first legally-binding climate treaty was the Paris Agreement in 2015. This Agreement resulted in commitment of countries to fight the multifaceted issue of climate change. The commitment presents responsibility of any country to efficiently pursue the goal of maintaining the rise in global temperature at least below 2°C in this century compared to the pre-industrial levels.

Although the Agreements are uniting countries around the globe toward one common goal of fighting climate change, the EU made a step further by implementing the first ETS in 2005. Its function is to aid Member States in achieving the emission reduction goal of the Agreements. Despite being the first such system in the world, its pilot Phase was a success as the system was well-functioning by the beginning of the first Kyoto commitment period 2008. The EU ETS served as an exemplary model for the following ETSs across the world. However, ETSs across the world differ in the sectors and gases covered, providing for a variety of carbon price points and price determinants accordingly.

This thesis aimed to identify dynamic relations of allowance price drivers in the EU ETS and attempted to discover new price determinants of the EU ETS. Based on that, I employed the Autoregressive Distributed Lag model (ARDL) to study the impact of exchange rates – USD/EUR and CNY/EUR, fossil fuel prices – natural gas, brent oil and coal, electricity price and the weather variable – heating degree days index on EU ETS allowance price. Since the analysis of identification of structural breaks offered an estimate of the break dates, the effect of EU Directive 2018/410 on allowance price was also investigated. The ARDL model was applied due to the advantages it offers when dealing with both stationary, non-stationary and also exogenous variables.

The main contribution of the thesis to the literature is the inclusion of exchange rates as explanatory variables in the regression of EU ETS allowance price. Furthermore, the time period used in the modelling exercise is the longest in comparison to comparable studies on the topic. This analysis uses the time period from July 2006 to December 2019, which extends over three Phases of the EU ETS. Considering an inclusion of three different categories of variables (economic, energy and weather conditions), the analysis provides a holistic perspective on EU ETS allowance pricing.

According to the result of this analysis, short- and long-run relationships between the explanatory variables and the EU ETS allowance price have been found. In the long-run, exchange rates USD/EUR and CNY/EUR, gas and electricity prices significantly affect the EU ETS allowance price. The exchange rates influence the allowance price in a different manner, where USD/EUR affects it positively and CNY/EUR negatively. This might be due to the influence, each of the respective countries want over their currencies. The exchange rate is, nevertheless, arguably one of the most important relative prices in the economy, thus significant effects were expected. Also expectedly, natural gas price negatively affects the allowance price since its combustion generates less emission than the other two fossil fuels. Moreover, electricity price positively affects the allowance price. This result supports the fact that European power-generation still uses fossil fuels as its main power-generation input. On the other hand, in the short-run, more categories of variables affect the EU ETS allowance price. Similarly to the long-run dynamics, CNY/EUR exchange rate, natural gas and electricity prices (current and lagged values) are deemed as significant allowance price determinants. Additionally, lagged value of the allowance price itself and the EU ETS Directive 2018/410 both positively influence the allowance price in the short-run. At first, the latter result is perceived as unexpected, however, beside revisions for the Phase IV, inclusion of maritime sector provides a relatively sizeable amount of additional emissions that are now covered under EU ETS.

Taking all of the findings into consideration, economic variables - exchange rates and energy variables - natural gas and electricity prices, show an impact on allowance price in the long-run as well as in the short-run. Moreover, the insignificant impact of coal and brent oil prices as two energy variables on the allowance price is not surprising because of the similar results of previous studies. Despite the findings this thesis provides, the exchange rate variable that shed a new light on the topic should be further investigated in other econometric models with abundance of model specifications. In order to establish the direction of causality among allowance price determinants, it is necessary to expand the analysis and use an appropriate causality test between variables. Nevertheless, this are supplementary steps which go beyond the scope of my research questions in this master's thesis.

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APPENDICES

Appendix 1: Povzetek (Summary in Slovene language)

Podnebne spremembe predstavljajo poglavitni problem našega časa. Kot globalni fenomen, so njegovi učinki opazni v vseh državah sveta. Učinki se kažejo v ekstremnih vremenskih razmerah in dogodkih, ki dokazujejo kako ranljiv je naš planet. Z nešteto negativnimi posledicami, so podnebne spremembe v svojem obsegu neprimerljive s katerikoli drugim naravnim pojavom. Kljub naravnemu pojavu toplogrednih plinov, je človeški vdor v naravo tisti, ki je povzročil in še naprej s katastrofalno hitrostjo vodi podnebne spremembe, ki postajajo vse bolj obsežne. V povezavi s tem je ekonomska znanost skušala odpraviti negativne eksternalije. Na zgledu manjših primerov in teorij se je izkazalo, da je najfleksibilnejši način učinkovite odprave negativnih eksternalij zahtevati od onesnaževalca, odpravo teh eksternalij, kjer je ta najbolj ekonomična. Za zasledovanje tako obsežnega pojava, kot so podnebne spremembe, se je pričelo mednarodno sodelovanje in s tem tudi pogajanja. Okvir konvencije Združenih narodov o podnebnih spremembah (UNFCCC) je leta 1992 začrtal skupni cilj in okvir za vse prihodnje sporazume. Sledil je Kjotski sporazum, ki je uvedel tri mehanizme – trgovanje z emisijami, Mehanizem čistega razvoja (angl. Clean Development Mechanism) in Skupni projekti (angl. Joint Implementation). Kljub obsežnim novostim, pa je bila prva pravno zavezujoča pogodba Pariški sporazum iz leta 2015, ki je prispeval k zavezi držav v boju proti obsežnemu problemu podnebnih sprememb. Omenjena zaveza predstavlja odgovornost vsake države, ki se je odločila za zasledovanje cilja, da v tem stoletju ohrani dvig svetovne temperature vsaj pod 2°C v primerjavi s predindustrijsko ravnjo.

Čeprav navedeni sporazumi združujejo države sveta k skupnemu cilju boja proti podnebnim spremembam, je Evropska Unija (EU) naredila korak dalje z izvedbo prvega sistema trgovanja s pravicami do emisij toplogrednih plinov (angl. ETS) v letu 2005. Naloga dotičnega sistema je pomagati državam članicam pri doseganju ciljev sporazumov pri zmanjševanju emisij. Glede na to, da je šlo za prvi takšen sistem na svetu, je bila pilotna faza uspešna, saj je bil sistem do začetka Kyotskega ciljnega obdobja v letu 2008 že operativen. EU ETS je služil kot zgleden model za sledeče ETS-je po vsem svetu. ETS-ji po svetu pa se razlikujejo tudi po zajetih sektorjih in plinih, kar se kaže v različnih cenah ogljika in njegovih dejavnikih.

Namen magistrske naloge je ugotoviti dinamična razmerja dejavnikov cene pravic do emisij v EU ETS in poskusiti odkriti nove determinante cen pravic do emisij. Na tej podlagi sem uporabila ekonometrični model ARDL preučevanja vpliva dveh deviznih tečajev – USD/EUR in CNY/EUR, cen fosilnih goriv – zemeljskega plina, nafte in premoga, cene električne energije ter vremenske spremenljivke – indeks ogrevalnih stopinjskih dni na ceno emisijskih kuponov EU ETS. Ker je analiza prisotnosti strukturnih prelomov prikazala obstoj ocenjenih datumov prelomov, je bil raziskan tudi vpliv EU Direktive 2018/410 na ceno emisijskih kuponov. Zaradi prednosti, ki jih ARDL model ponuja pri obravnavi tako stacionarnih in nestacionarnih, ter eksogenih spremenljivk, sem le-tega uporabila v analizi.

Glavni prispevek magistrskega dela literaturi je vključitev deviznih tečajev kot pojasnjevalnih spremenljivk v regresiji cene emisijskih kuponov EU ETS. Pri tem je časovno obdobje, ki je bilo uporabljeno pri modeliranju, najdaljše v primerjavi s primerljivimi študijami. V analizi sem uporabila časovno obdobje med julijem 2006 in decembrom 2019, ki se razteza čez tri faze EU ETS. Ob upoštevanju vključitve treh različnih kategorij spremenljivk (ekonomske, energetske in vremenske razmere) analiza ponuja celostno perspektivo določanja cen emisijskih kuponov v EU ETS.

Glede na rezultate moje analize so bila ugotovljena kratkoročna in dolgoročna razmerja med pojasnjevalnimi spremenljivkami in ceno emisijskih kuponov EU ETS. Dolgoročno, devizni tečaji USD/EUR in CNY/EUR, cene plina in električne energije pomembno vplivajo na ceno emisijskih kuponov EU ETS. Oba tečaja na ceno emisijskih kuponov vplivata v nasprotni smeri, pri čemer USD/EUR vpliva pozitivno, CNY/EUR pa negativno. To je lahko posledica vpliva, ki ga država želi imeti nad svojo valuto. Devizni tečaj je kljub temu nedvomno ena najpomembnejših relativnih cen v gospodarstvu, s čimer je njen vpliv na ceno emisijskih kuponov pričakovan. Prav tako pričakovano, cena zemeljskega plina negativno vpliva na ceno emisijskih kuponov, saj njegovo izgorevanje ustvarja manj emisij kot druga fosilna goriva. Nadalje, cena električne energije pozitivno vpliva na ceno kuponov. Ta rezultat podpira dejstvo, da evropska proizvodnja električne energije kot svoj glavni vir še vedno uporablja fosilna goriva. Glede na kratkoročna razmerja, več kategorij spremenljivk vpliva na ceno emisijskih kuponov EU ETS. Podobno dolgoročni dinamiki, veljajo za pomembne dejavnike cen emisijskih kuponov tečaj CNY/EUR, cene zemeljskega plina in električne energije (trenutne vrednosti in vrednosti zamikov). Dodatno na cene kuponov vpliva tudi vrednost zamika v sami ceni kuponov in EU Direktiva 2018/410, ki kratkoročno pozitivno vplivata na ceno emisijskih kuponov v EU ETS. Na prvi pogled je slednji rezultat nepričakovan, vendar pa je poleg sprememb za četrto fazo, vključitev pomembnega sektorja kot je pomorski, zagotavlja razmeroma velik delež dodatnih emisij, ki so sedaj zajete v EU ETS.

Ob upoštevanju vseh ugotovitev, ekonomske spremenljivke – devizna tečaja USD/EUR in CNY/EUR ter energetske spremenljivke – cene zemeljiskega plina in električne energije izkazujejo dolgoročen in kratkoročen vpliv na cene emisijskih kuponov v EU ETS. Poleg tega, nepomemben vpliv cen premoga in nafte kot dveh energetskih spremenljivk na ceno emisijskih kuponov ni presentljiv zaradi podobnih rezultatov prejšnjih študij. Kljub ugotovitvam te naloge, bi morali vpliv deviznih tečajev kot novost v raziskovanju dejavnikov cen emisijskih kuponov v EU ETS, raziskati tudi s pomočjo drugih ekonometričnih modelov s čim več specifikacijami modelov. Za določitev smeri vzročnosti dejavnikov cen emisijskih kuponov, pa je potreba razširitev analize in uporaba primernega testa vzročnosti med spremenljivkami. Vendar pa dotične razširitve predstavljajo dodatne korake, ki presegajo obseg mojih raziskovalnih vprašanj v tej magistrski nalogi.

Appendix 2: Relevant studies with approaches, time periods, data frequencies and variables used

Authors	Approach	Time period	Data frequency	Variables
Mansanet-Bataller, Pardo and Valor (2007)	LS	January 2005 – November 2005	Daily	• CO2 forward price • Brent futures price • Natural gas futures price • Coal forward price • Switch price (between gas and coal) • Indexes for extreme temperatures and precipitation in Europe
Alberola, Chevallier and Chèze (2008)	OLS	July 2005 – April 2007	Daily	• EUA spot price • Brent futures price • Natural gas futures price • Coal futures price • Clean dark spark • Clean spark • Switch price • Temperature average indexes
Hintermann (2010)	ARCH	January 2005 – June 2007	Daily	• EUA OTC price • Natural gas futures price • Coal price • Temperature and precipitation averages • Nordic Reservoir levels
Nazifi and Milunovich (2010)	VECM	June 2005 – April 2007	Daily	• EUA spot and futures prices • Brent oil price • Natural gas price • Coal price • Electricity price • Daily temperature for Munich

Peri and Baldi (2011)	TVECM	January 2008 – May 2009	Daily	• EUA futures price • Brent oil spot price
Creti, Jouvet and Mignon (2012)	DOLS	June 2005 – December 2010	Daily	• EUA futures price • Euro Stoxx 50 • Brent oil futures price • Switch price • Natural gas price • Coal price
Castagneto-Gissey (2013)	VECM	July 2009 – May 2011	Daily	• EUA spot price • Natural gas spot price • Electricity spot price • Oil spot prices
Hammoudeh, Khuong Nguyen and M. Sousa (2014)	BSVAR	August 2006 – November 2013	Monthly and daily	• EUA spot price • Crude oil spot price • Natural gas spot price • Coal price • Electricity price
Koch, Fuss, Grosjean and Edenhofer (2014)	OLS	January 2008 – October 2013	Monthly	• EUA futures price • Switch price • Natural gas futures price • Coal futures price • Stoxx Europe 600 index • ESI • Wind/solar based electricity production • Hydro based electricity production • Amount of issued CERs
Chung, Jeong and Young (2018)	VECM	January 2013 - December 2017	Monthly	• EUA futures price • Coal price • Natural gas futures price • Electricity futures price • Brent oil futures price • IPI

				• ESI • Euro Area Bank Lending index • CER futures price • Avg. temperature indexes (min. and max.) • Avg. precipitation index
Uludağ (2019)	ARDL	January 2008 – December 2017	Monthly	• EUA futures price • Coal futures price • Brent oil futures price • Natural gas futures price • Switch • IPI • ESI • HDD weather variable • Stoxx 600 oil and gas index