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Final Thesis

An Evaluation of the European Union Emissions Trading System: The Importance of Including Methane Emissions Along the Supply Chain of Natural Gas and Crude Oil

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Questa tesi esamina l'efficienza ambientale ed economica del Sistema europeo di scambio di quote di emissione di gas a effetto serra, in inglese European Union Emissions Trading System (EU ETS). Questo sistema rappresenta il principale strumento adottato dall'Unione Europea dal 2005 per raggiungere gli obiettivi di riduzione delle emissioni di CO2 nei principali settori industriali e nel comparto dell'aviazione. L'EU ETS è suddiviso in quattro fasi. La prima fase copre un periodo dal 2005 al 2007, la seconda dal 2008 al 2012, la terza fase ha invece interessato un periodo dal 2013 al 2020. La quarta e attuale fase è iniziata nel 2021 e finirà nel 2030. Attualmente il Sistema interessa in tutta Europa oltre 11.000 impianti industriali e circa 600 operatori aerei. Il meccanismo è basato sullo schema di *cap-and-trade*, ovvero è fissato un tetto massimo complessivo di emissioni di CO2, il *cap*, che i settori interessati possono emettere, a cui corrisponde un numero equivalente di quote. Solitamente una quota corrisponde a 1 tonnellata di CO2 equivalente. Inoltre, queste quote possono essere acquistate e/o vendute sull'apposito mercato, il *trade*. Infatti, spesso avviene uno scambio di queste quote tra le industrie partecipanti perché accade che, per esempio, un'industria ha un numero troppo basso di quote per la sua produzione e quindi ne acquista di ulteriori da un'altra che invece ne ha un numero più elevato. Le quote possono essere allocate a titolo oneroso o gratuito. Nel primo caso sono vendute attraverso aste pubbliche nelle quali le industrie le acquistano per compensare le proprie emissioni. Nel secondo caso, le quote sono assegnate gratuitamente dalle industrie. Questo sistema si è rivelato controproducente perché non ha portato ad una riduzione delle emissioni di CO2 e ha un elevato rischio di delocalizzazione delle produzioni in Paesi con standard ambientali meno stringenti rispetto a quelli dell'Unione Europea, specialmente durante le prime due fasi del Sistema.

Gli obiettivi di questa tesi sono l'analisi dell'efficienza del Sistema europeo di scambio di quote di emissione di CO2, e una proposta di cambiamento strutturale per renderlo più efficiente ed efficace da un punto di vista ambientale ed economico. Le domande a cui questo elaborato risponderà saranno le seguenti. Quanto è stato efficiente l'EU ETS a raggiungere i suoi obiettivi di riduzione di emissioni? Quali sono i cambiamenti strutturali per migliorare il sistema? Per rispondere a questi quesiti la tesi è stata divisa in tre capitoli. Il primo capitolo introduce la tesi riportando l'ampio e molto discusso tema del cambiamento climatico e del riscaldamento globale. Questo, infatti, sarà il filo conduttore dell'elaborato in quanto l'EU ETS è stato fondato proprio con l'obiettivo di contrastare questi fenomeni ambientali partendo dalla riduzione delle emissioni di CO_2. Il secondo capitolo descrive fase per fase il Sistema, analizzandolo da un punto di vista economico; quindi, basato sull'andamento dei prezzi dei permessi delle quote, l'impatto sul profitto e sulla competitività delle industrie interessate. Di maggiore importanza sarà l'analisi dal punto di vista ambientale, ovvero se l'EU ETS ha contribuito a ridurre il numero di emissioni di CO_2 nelle varie industrie. Questo secondo capitolo è molto importante in quanto la comprensione del meccanismo del Sistema permetteranno l'analisi della sua efficienza durante gli anni, e successivamente permetterà di proporre dei cambiamenti strutturali nel terzo capitolo. Quest'ultimo capitolo propone infatti un possibile miglioramento dell'EU ETS basato sull'importanza di includere nel *cap* del meccanismo anche le emissioni di metano, specialmente quelle generate durante la catena di approvvigionamento dei combustibili fossili per la produzione industriale ed energetica, come il gas naturale ed il petrolio greggio.

Il mio interesse per l'analisi del Sistema di scambio di quote di emissione di CO_2 è maturato durante il corso di International Political Economy tenuto dal Professor Valerio Dotti, e per questo ne ho voluto approfondire la sua storia durante gli anni con i suoi punti di forza e di debolezza. Inoltre, l'attuale ed allarmante situazione ambientale e climatica è un argomento per cui nutro molto interesse. Pertanto, analizzare nel dettaglio le politiche europee che possono contrastare e migliorare il fenomeno del cambiamento climatico rappresentava l'unione di questi due interessi.

Come anticipato, questa tesi è suddivisa in tre capitoli. Il primo capitolo propone un'introduzione sull'argomento del cambiamento climatico. Il capitolo infatti inizia descrivendo come questo fenomeno si è sviluppato durante gli anni e quali sono stati i principali fattori scatenanti. La Rivoluzione Industriale nel 1750 rappresenta un possibile inizio del cambiamento climatico dovuto alle crescenti attività economiche ed industriali nelle quali venivano bruciate grandi quantità di combustibili fossili come carbone e petrolio, che hanno portato gradualmente ad un aumento delle emissioni di gas serra nell'atmosfera. Nei secoli questo processo non si è più fermato, crescendo invece sempre di più e raggiungendo la situazione drammatica attuale, nella quale la temperatura terrestre è aumentata di quasi 2°C dalla fine del 1800 ad oggi. Per questo motivo sono stati stabiliti dei "confini del pianeta", ovvero nove aree critiche da monitorare e controllare con regolarità perché il loro superamento potrebbe portare a conseguenze irreversibili e catastrofiche per la sostenibilità del pianeta terra. Le nove aree critiche sono le seguenti: la riduzione dell'ozono presente nell'atmosfera, la perdita di biodiversità, l'inquinamento da sostanze chimiche, il cambiamento del clima, l'acidificazione degli oceani, l'utilizzo delle acque dolci, la modifica del sistema agrario, il ciclo dell'azoto e del fosforo, il rilascio di aerosol nell'atmosfera. Tre di questi confini sono già stati superati e sono il cambiamento del clima, la perdita di biodiversità, e il ciclo dell'azoto e del fosforo. Il primo capitolo segue riportando nello specifico quali sono le principali conseguenze ambientali, sociali, ed economiche del superamento del confine del cambiamento climatico. Questo a livello ambientale ha portato ad una graduale perdita di biodiversità, fino anche alla loro estinzione. Il cambiamento climatico dovuto alla costante attività umana ha portato ad una sempre maggiore deforestazione e distruzione del terreno. Inoltre, il graduale aumento delle temperature atmosferiche ha portato allo scioglimento dei ghiacciai, che di conseguenza ha alzato il livello dei mari. Il riscaldamento globale inoltre ha reso più acido il pH degli oceani, mettendone a rischio la fauna marina. Il cambiamento climatico ha effetti negativi anche sulla salute e la produttività degli esseri umani, oltre a rallentare la produzione economica e quindi la crescita di un paese. La seconda parte del primo capitolo posiziona poi il fenomeno del cambiamento climatico sotto una luce più economica grazie all'Economia dell'ambiente. Questa branca economica applica i principali principi economici agli attuali problemi ambientali, come la teoria dell'esternalità e la risorsa di proprietà comune. Il primo capitolo poi conclude riportando le principali azioni messe in atto dall'Unione Europea per contrastare gli effetti negativi del cambiamento climatico, dalla prima Conferenza mondiale sul clima nel 1979, alla più recente 26ª Conferenza sul clima delle Nazioni Unite (COP26) tenutasi a Glasgow nel 2021. Il capitolo riporta inoltre gli effetti della tassa sul carbonio nel contrastare l'aumento delle emissioni di gas serra. Infine, riporta quelli del sistema di scambio delle quote di emissioni di CO2 con l'EU ETS. Il primo capitolo si conclude con il confronto dei punti di forza e di debolezza di quest'ultime due azioni.

Il secondo capitolo si apre con la preparazione dell'EU ETS prima di essere implementato nel 2005. Successivamente, presenta l'andamento dei prezzi dei permessi, il metodo di allocazione, la riduzione delle emissioni, e gli effetti economici di ciascuna fase dell'EU ETS negli anni. Complessivamente, la prima e la seconda fase hanno rappresentato le fasi di prova del Sistema, mentre la terza e l'attuale quarta fase hanno dato risultati migliori per quanto riguarda la riduzione delle emissioni e degli effetti economici positivi per le industrie interessate. I problemi principali durante le prime fasi erano dovuti al metodo di allocazione dei permessi perché dati gratuitamente ed in eccessive quantità. L'andamento dei prezzi dei permessi ha rappresentato un altro problema, in quanto sono stati complessivamente bassi, e questo non ha incentivato a ridurre le emissioni ed investire in tecnologie a basse emissioni di carbonio. Dalla seconda fase le quote vengono assegnate con procedura all'asta, contrastando così il problema dell'eccessiva allocazione dei permessi. Per quanto riguarda la riduzione delle emissioni di CO2, la seconda fase è stata migliore rispetto alla prima, ma in parte a causa della crisi economica del 2008, che ha portato ad una netta riduzione delle attività economiche. La terza fase, iniziata del 2013, è stata più efficiente nella riduzione delle emissioni grazie all'implementazione di una serie di riforme. Prima fra tutte, il tetto di emissioni è stato notevolmente ristretto, introducendo anche la *Linear Reduction Factor* (LRF), ovvero una riforma nata nel 2014 che ha ristretto il *cap* ogni anno fino al 2020. Inoltre, solo il 43% di permessi sono stati allocati gratuitamente, mentre il restante è stato acquistato all'asta. Grazie all'entrata in vigore dell'Accordo di Parigi nel 2015, i prezzi dei permessi hanno subito una crescita significativa, incentivando maggiormente la riduzione delle emissioni. La terza fase si conclude però con un crollo dei prezzi dovuto allo scoppio della pandemia del Covid-19 nel 2020. Nonostante questo, hanno ripreso velocemente a crescere con la ripresa economica l'anno seguente. La quarta e attuale fase è stata ulteriormente perfezionata grazie anche agli errori fatti nelle fasi passate e all'importanza ed attenzione alla sostenibilità sempre più sentita nell'Unione Europea. Il tetto delle emissioni è stato ulteriormente ristretto, i prezzi dei permessi sono nettamente aumentati, e sono state introdotte riforme più rigide e con obiettivi climatici più ambiziosi. Al momento, infatti, il numero di emissioni ridotte è molto più alto.

Nonostante il progressivo miglioramento dell'EU ETS, ci sono ancora molti aspetti da migliore, tra cui l'inserimento di un ulteriore gas serra, il metano e le sue emissioni durante la catena di approvvigionamento dei combustibili fossili. Sarà questo, infatti, il focus del terzo ed ultimo capitolo di questo elaborato, che proporrà questo miglioramento strutturale del Sistema attraverso un approccio economico con lo sviluppo dell'equazione della funzione di domanda. Per sostenere questa tesi, il terzo capitolo ruota attorno ad un esempio in cui un'industria energetica italiana importa dall'Algeria due combustibili fossili, il gas naturale e il petrolio greggio. La scelta di quest'ultimo paese è data dal fatto che, a seguito dello scoppio della guerra tra Ucraina e Russia nel 2022, la rete di importazioni di fonti energetiche è cambiata radicalmente. La Russia, infatti, non ha più il primato di esportazioni di gas e petrolio, ma al suo posto sono subentrati altri paesi EU ed extra-EU, tra cui l'Algeria, in particolare in relazione con l'Italia. Il capitolo inizialmente presenta una descrizione di come si sviluppa la catena di approvvigionamento del gas naturale e del petrolio dall'Algeria all'Italia. Successivamente sono riportati i dati delle emissioni di metano sia durante la combustione di queste fonti in Italia, sia lungo la catena di approvvigionamento in Algeria. L'analisi di questi dati riporta un risultato piuttosto inaspettato in quanto il gas naturale, se da un lato è considerato più "pulito" perché, quando brucia ha meno emissioni, d'altra parte risulta molto più inquinante quando viene inclusa la sua catena di approvvigionamento, rispetto al petrolio. Questi dati poi saranno usati nell'equazione della funzione di domanda per verificare quanto cambia la domanda di gas naturale e petrolio una volta che vengono incluse anche le emissioni di metano delle catene di approvvigionamento.

La raccolta dei dati sulle emissioni di metano e lo sviluppo dell'equazione della funzione di domanda porteranno infatti a confermare l'importanza di includere le emissioni di metano durante la catena di approvvigionamento in quanto questo gas serra risulta molto più inquinante nel breve e lungo termine rispetto all'anidride carbonica. Pertanto, la proposta di questa tesi è che, per ottenere dei risultati più efficaci nella riduzione delle emissioni di gas serra, l'EU ETS dovrebbe includere nel tetto di emissioni il metano, analizzandole all'interno della catena di approvvigionamento dei combustibili fossili usati dalle industrie interessate nel Sistema.

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Introduction

Over the last decades, humanity has been facing the most pressing issue: climate change. The scientific community has been warning governments and policymakers all over the world that climate change is extremely likely due to human activities that have increased atmospheric carbon dioxide and other greenhouse gas emissions (Omolere, 2024). As these emissions grow at an ever-increasing rate, their accumulation is leading to catastrophic consequences for the earth's ecosystems, the global climate patterns with increasingly warmer temperatures, and the economies and communities globally (Omolere, 2024). Carbon dioxide and other GHG emissions' major contributors are burning fossil fuels, such as coal, oil, and natural gas across transportation, industrial processes, agriculture, and most importantly electricity generation (Omolere, 2024). Countries all over the world have thus taken several measures to tackle climate change's threats (Cifuentes-Faura, 2022). Among them, the European Union has been one of the most active in environmental protection with the development of policies to preserve citizens' health and well-being and protect natural resources (Cifuentes-Faura, 2022). Indeed, over time, the European Union has demonstrated to have the highest environmental standards in the world through several developments and advances in environmental protection (Cifuentes-Faura, 2022). The Kyoto Protocol and the Paris Agreement represent two pivotal international environmental treaties aiming to reduce greenhouse gas emissions and keep the global temperature below 2°C above pre-industrial levels, respectively (Gupta, 2010; Cifuentes-Faura, 2022). According to the Climate Action Tracker, the European Union is rated a "medium" for its commitment to reducing emissions (Harris and Roach, 2017). Furthermore, the European Green Deal was approved by the European Commission in 2020 with the goal of making the EU climate neutral by 2050. This plan finances the circular economy, building renovation, biodiversity, farming, a sustainable food system, and innovation (Cifuentes-Faura, 2022). Concerning the concept of circular economy, in 2019 the European Union created the first Action Plan for the Circular Economy which consists of making sustainable products the standard in the EU, ensuring that goods on the market last longer, and are simpler to reuse and recycle (Cifuentes-Faura, 2022).

The central topic of this thesis, and another significant climate action, is the European Union Emissions Trading System, a cap-and-trade scheme implemented by the European Commission in 2005 (Venmans, 2012). This scheme has a cap set by the government, which covers the total amount of greenhouse gases that can be emitted by the participating installations (The Core, n.d.). This cap is expressed in emission allowances, where one allowance gives the right to emit one tonne of CO2 equivalent (European Commission, n.d.). Then the government gives permits to the polluting firms. The latter may trade their permits with other firms because of an excess or scarce number of permits, depending on each firm's emissions. Finally, the firms submit permits to the government to cover their emissions. For each tonne of emissions produced, firms are asked to provide one permit to the government (The Core, n.d.). In this way, European firms are encouraged to cut their CO2 emissions and invest in low-carbon technologies (The Core, n.d.). The European Union Emissions Trading System has been divided into four phases. The first one covered the period from 2005 to 2007, the second phase from 2008 to 2012, the third phase started in 2013 and ended in 2021, and the fourth and ongoing phase started in 2021 and will cover a period until 2030.

This thesis aims to answer the following research questions: *How effective is the European Union Emissions Trading System in meeting its goals? What could be the structural changes to improve this system?* It first describes each of the four phases through an analysis of the carbon allowances price, the number of emissions reduced, and the economic impact on the firms within the EU ETS. Then, this dissertation highlights the challenges that the EU ETS is still facing today and proposes a measure to improve the system, in terms of its environmental and economic effectiveness. This thesis focuses on the importance of including methane fugitive emissions generated along the supply chain of fossil fuels (Monciatti et al., 2021). Currently, the system covers only the CO2 downstream segment emissions, for instance, those when fossil fuels are burned. To prove this thesis, an Italian power plant is taken as an example. This uses natural gas and crude oil imported from Algeria to produce electricity. This example is based on some recent data in which Italy's main importer of these fossil fuels has become Algeria, especially in the aftermath of the Ukraine and Russia war in 2022 (Butt, 2023). Thus, to develop the proposal of including methane emissions along the supply chain of natural gas and crude oil, a demand function equation is built by using the data taken from the Algeria National Inventory Report of 2020 (Ministry of the Environment and Renewable Energy, 2023), for the values of the Algerian production and transportation segments of natural gas and crude oil, namely the upstream and midstream segments. Furthermore, the International Energy Agency (2021) values are instead used for the Italian downstream segment of these two fossil fuels. Once these values are summed up and used to develop the equations, the outcomes prove the initial aim of this thesis and confirm the need to include the supply chain methane emissions in the EU ETS.

This thesis is divided into 3 chapters. Chapter 1 introduces the topic of global climate change. The first three Sections explore the topic of global climate change from a more scientific point of view, dealing with the planetary boundary approach and the impact of climate change on natural resources, society, and economy. The fourth Section presents instead the topic of climate change from an economic perspective, by introducing the field of Environmental Economics and its core principles. The fifth Section examines the options to combat global climate change adopted by economists and policymakers, namely several international treaties, the carbon tax, and most importantly the cap-and-trade system, especially the European Union Emissions Trading System.

Chapter 2 delves into the analysis and assessment of each of the four phases of the EU ETS. The evaluation is based on how this cap-and-trade scheme was successful in reducing CO2 emissions, and whether it affected the economic performance of the participating sectors. In detail, each phase's analysis is based on five factors. The first one is the price trend of the carbon permits during that phase. The second factor is the allocation of allowances method, which can be by grandfathering, as for the first two phases, or by auctioning of allowances as for the third and fourth phases. The number of CO2 emissions reduced in each phase represents the third factor to assess the EU ETS. The fourth factor evaluates the impact on the economic performance that the EU ETS has on the firms within this system. The fifth and last factor evaluates their competitiveness after the introduction into the EU ETS.

Chapter 3 discusses the need to include the supply chain emissions of fossil fuels, and other greenhouse gases, particularly methane in the EU ETS. To illustrate this issue, the chapter first reports the system's current challenges. Then, as above mentioned, the Italian power plant within the EU ETS is taken as an example, and thus the method for the calculation and price of CO2 emissions in the power sector is explained. The first values for the demand function equation are reported in the third section and correspond to the downstream Italian emissions. After a brief representation of the current fossil fuel import situation in the European Union, the chapter delves into the description of the upstream and midstream supply chains of natural gas and crude oil and the related issue of flared, vented, and fugitive emissions. Following this, Section 3.8 describes and counts the fugitive emissions from the Algerian natural gas and crude oil supply chains to Italy.

These results are used to develop the demand function in Section 3.9, which will show how the choice of the Italian energy industry will eventually change after introducing the supply chain emissions, and whether the EU ETS is effective in the GHG emissions reduction. The final section of the chapter provides some suggestions to improve the EU ETS and concludes.

1. Global Climate Change

This first chapter will introduce and report on how global climate change has been affecting the Earth's ecosystems, as well as the society as a whole and its economy. The first section will briefly introduce the topic of global climate change. The second one will deal with the planetary boundary approach. Following this, the next section will present the impacts of global climate change, firstly on the natural resources, and then on the society and the economy. Finally, the fourth section will tackle the topic of global climate change from an economic perspective. It will present the field of Environmental Economics and its core principles. Then, the following subsections will deal with the options to combat global climate change adopted by economists and policymakers.

1.1. Global Climate Change: An Introduction

The Earth has undergone many periods of significant environmental change. The Holocene is one of the geologic periods known for its unusual stability for the past 10,000 years. This is characterized by the rise, development, and prosperity of human civilizations (Rockström et al., 2009). However, such stability may now be under threat. Indeed, Rockström et al. (2009) report that during the Holocene, an environmental change occurred naturally, and the Earth's regulatory capacity maintained the conditions that enabled human development, such as regular temperatures, freshwater availability, and biogeochemical flows. However, since the start of the Industrial Revolution in 1750, human activities rapidly increased the emissions of greenhouse gases to the atmosphere by burning fossil fuels, including coal and oil. Over time this process did not slow down and led to dramatic environmental consequences. Now the Earth's average surface temperature rose around 1.18 °C from the late 1800s to 2020, leading to the current phenomenon of climate change, also called global warming (NSW Government, 2022). The main issue is that the warming of the Earth is not only changing the surface's temperature, but it is changing the climate and the Earth's ecosystems as a whole (NSW Government, 2022). This led to a new geological epoch, the Anthropocene, in which human beings are more and more exposed to the threats of climate change and need to do everything possible to slow down this process (Steffen et al., 2015; Harris and Roach, 2017). Eventually, this led to the introduction of local and regional boundaries or constraints on what could be emitted to and extracted from the environment and on how much the environment could be changed by direct human modification (Steffen et al., 2015). The next section will deal with the planetary boundary approach which defines a safe operation for human activities by respecting the Earth's systems.

1.2 The Planetary Boundaries

To prevent human activities from causing irreversible environmental change, the planetary boundary approach has been established (Rockström et al., 2009). It aims to define a safe operating space for human societies to develop and thrive, based on the planet's biophysical systems and processes (Rockström et al., 2009). Many subsystems of Earth are particularly sensitive around threshold levels of certain key variables. If these thresholds are crossed, then subsystems could shift into a new state, often with deleterious or potentially disastrous consequences for humans (Rockström et al., 2009). Thus, nine Earth-system processes and their associated thresholds are identified. They are climate change, biodiversity loss (terrestrial and marine), interference with the nitrogen and phosphorus cycles, stratospheric ozone depletion, ocean acidification, global freshwater use, land system, change chemical pollution, and atmospheric aerosol loading (Rockström et al., 2009). The analysis of different authors of this dissertation's literature suggests that three of these planetary boundaries are already being crossed: climate change, biodiversity loss and interference with the nitrogen and phosphorus cycle (Rockström et al., 2009; Steffen et al., 2015; Costanza et al., 2015).

Two different thresholds set the base for the climate change boundary, and they separate qualitatively the climate-system states. They are the atmospheric concentration of carbon dioxide and the radiative forcing. The atmospheric CO2 concentrations should not exceed 350 parts per million by volume and the radiative forcing should not exceed 1 watt per square metre above pre-industrial levels (Rockström et al., 2009). The current CO2 concentration stands at 387 parts per million by volume and the change in radiative forcing is 1.5 W m $^{-2}$. Thus, it seems that the thresholds have already been exceeded. Indeed, transgressing these boundaries will increase the risk of irreversible climate change, such as the loss of major ice sheets, accelerated sea-level rise and abrupt shifts in forest and agricultural systems (Rockström et al., 2009). However, there is still some uncertainty about the precise rates of change and the extent of potential impacts (Costanza et al., 2015). One thing is sure, future projections of climate change depend on the path of future emissions. Even if all emissions of greenhouse gases ended today, the world would continue warming for many decades, and effects such as sea-level rise would continue for centuries, because the ultimate environmental effects of emissions are not realized immediately (Harris and Roach, 2017).

The second already exceeded planetary boundary is biodiversity loss. Species extinction is a natural process that would still happen in the absence of human activity (Rockström et al., 2009). However, biodiversity loss in the Anthropocene has accelerated massively. Today, the species' extinction rate is estimated to be 100 to 1,000 times more than what could be considered natural (Rockström et al., 2009). As seen for climate change, human activities are the main cause of the acceleration (Rockström et al., 2009). Biodiversity loss can occur at the local to the regional level, but it can also have effects at the global level. This is because the change in land use, such as converting natural ecosystems into agriculture or urban areas or introducing new species into land and freshwater environments, can have far-reaching implications for ecosystem functionality and services, and thus increase the vulnerability of terrestrial and aquatic ecosystems. In the long term, it can cause permanent changes in the biotic composition and functioning of Earth's ecosystems (Costanza et al., 2015).

The third planetary boundary to be exceeded is interference with the nitrogen and phosphorus cycle. Modern agriculture is the major cause of environmental pollution due to the large-scale use of nitrogen and phosphorus, which can cause abrupt shifts in the subsystems of the Earth (Rockström et al., 2009; Costanza et al., 2015).

Although three boundaries have been overstepped, they should be controlled and kept under a certain level and the other seven boundaries should not be exceeded. Furthermore, since many of the boundaries are linked, exceeding one means having implications for others and this can create destabilising feedback. This has profound implications for global sustainability because it emphasizes the need to address multiple interacting environmental processes simultaneously (Rockström et al., 2009; Costanza et al., 2015).

1.3 The Impacts of Global Climate Change

In section 1.2, it was observed that climate change is one of the planetary boundaries that has been exceeded, now these next subsections will describe what are the impacts and consequences of this.

1.3.1 The Impacts of Global Climate Change on Natural Resources

The impacts of climate change are many and diverse and they also depend on the geographic area (Tol, 2014). The biggest climate change impact will be seen for marginalized species and, in general, for global biodiversity (Tol, 2014). It is continuing to decline, with substantial and ongoing losses of populations, species, and habitats, and many of them are at the edge of survival (Harris and Road, 2017). Any other change could push them to extinction or dramatically expand their ecological niche (Tol, 2014). Harris and Roach (2017) provide a concrete example regarding vertebrate populations. The latter has declined by 30 per cent since 1970, and up to two-thirds of species in some taxa are now threatened with extinction. Declines are most rapid in the tropics, in freshwater habitats and for marine species utilized by humans. The authors (2017) report a future scenario in which 15–37 per cent of species would be "committed to extinction" by 2050. What is more, the percentage of species that will become extinct due to climate change would only be 5 per cent if the 2°C target is met, but 16 per cent if nothing is done (Harris and Road, 2017).

The land will be considerably affected by climate change. Harris and Roach (2017) report that "deforestation and forest degradation alone are likely to cost the global economy more than the losses of the 2008 financial crisis". The main issue is that the current economic system is built on the idea of perpetual growth and seems to be unsustainable within an ecological system that is bound by biophysical limits. Agriculture and forestry are the two largest categories of human land impacts and are evident in 83 per cent of the world's total land area, and in 98 per cent of the land area where it is possible to grow major crops (Harris and Roach, 2017). Moreover, a 2010 analysis, reported by the two authors, concludes that there is still considerable potential to increase yields. Indeed, the current production efficiency of wheat is estimated to be only 64 per cent of its global potential. The efficiency of corn production is even lower: only 50 per cent of its potential. Besides deforestation and land degradation, agriculture uses a serious number of fertilizers, pesticides, and irrigation water, which have negative environmental consequences (Harris and Roach, 2017). On the other hand, forests cover 31 per cent of the world's land area. The global deforestation rate has slowed since the 1990s, with annual forest loss declining from 16 million to 13 million hectares. However, forest trends vary dramatically in different parts of the world (Harris and Roach, 2017).

Sea level rise represents another major environmental issue due to global climate change, especially because of the increasing CO2 emissions in the atmosphere that warms the temperatures. This phenomenon heats water which consequently melts glaciers and ice sheets. The impact of rising seas threatens numerous coastal areas. For instance, the U.S. government has identified 31 Alaskan towns and cities at imminent risk, and cities in Florida are already experiencing significant damage from a major increase in flooding (Harris and Roach, 2017). The increased CO2 in the atmosphere results also in ocean acidification (Harris and Roach, 2017). This lowers the pH of the ocean, making it more acidic. More acidic water leads to the corrosion of minerals which many marine creatures rely on to build their protective shells and skeletons (Harris and Roach, 2017). The coral reef is another victim of ocean acidification, because corals can form only within a narrow range of temperatures and acidity of seawater. The year 2015 saw a record die-off of coral reefs, known as coral bleaching, due to a combination of the most powerful *El Niño* (Pacific warming) climate cycle in a century and water temperatures already elevated due to climate change (Harris and Roach, 2017).

1.3.2 The Impacts of Global Climate Change on the Society and the Economy

Climate change can also affect welfare and society in different ways, and consequently economic growth. Firstly, climate change affects human health through nutrition, air pollution, and vector-borne diseases (Tol, 2014). The increasing temperatures make people more tired and less able to work, especially outdoors. Cold negatively affects people as well. During cold weather, people group indoors, allowing infectious diseases to spread more easily (Tol, 2014). This harms labour productivity and thus impacts the total output as well (Tol, 2014). Climate change also has impacts on economic productivity. For instance, crops grow less if it is hotter and drier (Tol, 2014). Moreover, climate change can affect capital depreciation. More frequent floods, for instance, would wash away bridges, roads, and buildings. This implies that there is less capital and thus less output and investment. This also leads to more investment going towards replacing capital and less towards expanding the capital stock. Therefore, climate-change-related natural disasters have several effects on the economy (Tol, 2014). Economic activity is disrupted when a natural disaster strikes, and input factors are destroyed. Thus, a phase of recovery begins. However, according to the Bastiat's broken window fallacy, the money spent on repairing the damage of a natural disaster does not represent an increase in economic output and economic welfare (Tol, 2014). That is, if the money is spent on repairing a broken window, the opportunity cost is that individuals cannot spend money on other more productive goods, and this doesn't increase overall output but maintains the existing situation (Tol, 2014). Therefore, climate change affects labour and economic productivity on many levels, and consequently, this leads to slow development and economic growth.

It is noteworthy to say that climate change affects societies and economies in different ways. Indeed, its effects will fall most heavily upon poor countries of the world due to their geography, their stronger dependence on agriculture and because with fewer resources comes greater vulnerability (Stern, 2006). Regions in Africa will face severely compromised food production and water shortages, due to the shrinkage of their water sources. Coastal areas in South, East, and Southeast Asia will be at great risk of flooding due to the sea level rise. What is more, a drier climate will cause much damage to forests and agricultural areas in Tropical Latin America, while in South America the variation in the precipitation patterns and the disappearance of glaciers will deeply affect water supply (Harris and Roach, 2017). Despite poorer countries being the most affected by climate change adversities, they have fewer aids and means to cope with them and implement preventive measures (Harris and Roach, 2017). Moreover, richer countries produce more CO_2 per capita than poorer ones because they have greater income per capita and the results are higher levels of production of goods and services, with associated impacts on the atmosphere (The Core, n.d.). Indeed, this difference can be observed in Figure 1.1. The United States has the highest rate among major countries, with 17 metric tons of CO_2 emissions per person, followed by Russia with an average of 10 tons. The other developed countries are in the range of 4 to 10 metric tons per capita. Most developing countries have low rates per capita, typically less than 4 tons of CO_2. However, China is the exception among developing countries, whose per capita emissions have grown to 6.6 tons (Harris and Roach, 2017).

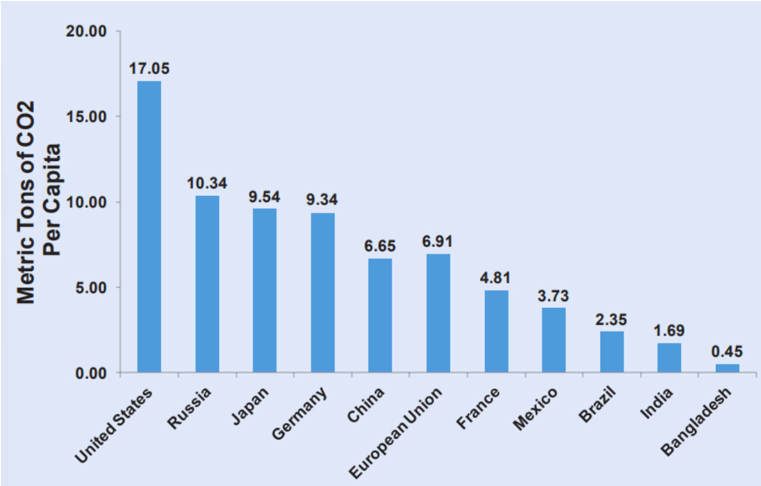

Figure 1.1 Per-Capita Carbon Dioxide Emissions by Country (Harris and Roach, 2017).

Indeed, if one looks at the distribution of CO2 emissions (Figure 1.2), the main emitter is China with 29 per cent, followed by the US with 15 per cent. The European Union accounts for 11 per cent, India 6 per cent, Russia 5 per cent and Japan only 4 per cent. The rest of the world accounts for a total of 30 per cent. Most of the future increase in carbon emissions is expected to come from nations with fast-growing economies, such as China and India (Harris and Roach, 2017).

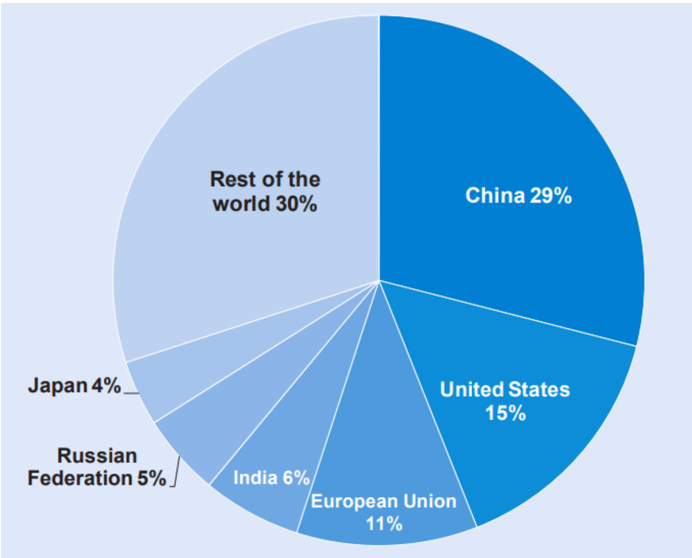

Figure 1.2 Percentage of Global CO2 Emissions by Country/Region (Harris and Roach, 2017)

This raises fundamental issues related to the concept of environmental justice. Indeed, this should imply an equitable sharing of both the burdens of climate change and the costs of developing policy responses (Harris and Roach, 2017).

1.4 Global Climate Change: An Economic Perspective

The abovementioned threat of climate change is raising many questions about the future of the Earth and the possible solutions to tackle this issue. One important component of the problem, which is rarely given enough attention, is an analysis of environmental issues from an economic perspective (Harris and Roach, 2017). Indeed, policymakers measure and sometimes reject, environmental protection policies, in terms of their economic costs (Harris and Roach, 2017). However, this process is a far cry from being simple because the protection of the environment implies taking a step back from ever-increasing economic growth. An example is the debate over the reduction of carbon dioxide emissions because the economic costs of such measures are too high (Harris and Roach, 2017). However, all economic development must affect the environment to some degree. The question is whether an "environment-friendly" economic development is possible. To answer this issue and many others, Environmental Economics is a field of a certain influence and importance (Harris and Roach, 2017).

1.4.1 Environmental Economics

Environmental Economics is a specific branch of economics which dates back only to the 1960s, simultaneously with the increasing awareness of environmental issues. Environmental Economics applies mainstream economic principles to environmental and natural resource issues (Harris and Roach, 2017). This indeed helps to use and manage finite resources in a way that serves the population, and at the same time, meets the concerns about the environmental impact (Chen, 2023). This next subsection will start with the assumption that the current market is not perfect. To be so, this would imply that every good and resource has an owner and a price, and the agents have full information on the options available to them. Or that people engage in mutually beneficial trade (Sterner and Coria, 2013). On the contrary, it will deal with the concept of market failure and its features. These basic theories are the starting point for most economic analyses of climate change (Stern, 2006).

1.4.1.1 The Theory of Environmental Externalities

Since the time of Adam Smith, economists have claimed that voluntary market exchanges between buyers and sellers "leave both parties better off than when they started" (Harris and Roach, 2017). But these market exchanges may also impact third parties other than buyers and sellers, either positively or negatively. This situation has been defined as an externality, and it is considered a market failure because an unregulated market fails to provide a good and useful result to society (Harris and Roach, 2017). Climate change is the most salient example of an externality because it entails the costs not paid for by some firms' greenhouse gas emissions and other parties suffer the consequences of this (Stern, 2006). The side effects of these firms' polluting activities occur because of a technical interdependence in consumption or production, they are not intentional, but at the same time, are difficult to avoid (Sterner and Coria, 2013).

Stern (2006) in his review reports that climate change is an externality with several features that distinguish it from other externalities. The first one is that it is global in its causes and consequences. Indeed, the impact of greenhouse gases is independent of where in the world they are emitted because they diffuse and accumulate in the atmosphere. The second feature is that its impacts are long-term and persistent over time. Once in the atmosphere, some greenhouse gases can stay there for hundreds of years and the natural carbon sinks, like oceans and forests cannot absorb them all. Then, climate change implies uncertainties and risks, and this has a significant effect on the global economy. Indeed, if no action is undertaken to prevent climate change, there could be potentially non-marginal changes to societies (Stern, 2006). The impacts of climate change are broad-ranging and interact with many economic dynamics, leading to policy-related issues. It is common to present climate change policies in terms of the marginal cost of carbon (SCC). This is the total damage of emitting an extra unit of greenhouse gas from now into the future, and marginal abatement cost (MAC). Their interaction implies that the SCC curve slopes downwards with increasing abatement. On the other hand, the MAC curve slopes upwards with increasing abatement as it is more costly. However, the optimum level of abatement should happen when the MAC equals the SCC (Stern, 2006). This path is difficult to calculate since climate change involves uncertainties about future emissions and stocks.

1.4.1.2 The Optimal Management of Public Goods

Another important instance of market failure is the allocation of public goods, which are natural resources and ecosystems entailing the features of being non-excludable and non-rival (Harris and Roach, 2017). The first feature means that it is impossible to exclude anyone from having access. The second one means that a certain good is available to everyone with no addition (Perman et al., 2003). However, the open-access character of natural resources can imply a certain level of rivalry, but not excludability. For instance, in an ocean fishery that lies outside a nation's territorial waters, no fishing boat can be prevented from exploiting the fishery because it is not subject to private property rights and there is no government with the authority to treat it as common property and regulate its exploitation. However, exploitation is rivalrous. If a fishing boat's catch increases, it means that other boats can catch less (Perman et al., 2003). Indeed, since these resources are not privately owned, markets cannot maintain them in adequate supply, and this leads to their overexploitation and depletion (Harris and Roach, 2017). Finally, Sterner and Coria (2013) report the distinction between different types of public goods. Pure public goods, as mentioned above, are non-excludable and non-rival. Impure public goods imply that the utility of one user is reduced by an increase in the number of other users. Lastly, club goods, also called mixed goods combine the features of private goods and public goods. They can be consumed by many individuals without diminishing the consumption of others, but exclusion is possible (Sterner and Coria, 2013).

1.4.1.3 Common Pool Resources (CPRs)

Common Pool Resources are goods that function as a hybrid between public and private goods because they are shared and available, but also scarce with a finite supply. As private goods, they exhibit rivalry but not excludability. Indeed, this might lead to overexploitation and might diminish the availability of that resource if everyone acts in their self-interest. Some Common Pool Resources have no formal owner, but typically some form of ownership is exercised, either collectively or by private individuals (Sterner and Coria, 2013). For this reason, CPRs are subject to the so-called tragedy of commons, that is the overexploitation and depletion of natural resources (Hardin, 1968).

1.5 Options to Combat Climate Change

This next section will present some options to combat climate change, especially in the European Union. The first subsection will briefly display a chronological order of the different environmental policies implemented at the European level from 1979 to today. The second subsection will focus on the carbon tax, whereas the third one on the topic of this dissertation: the cap-and-trade system. The last subsection will compare these two latter options.

1.5.1 Climate Change Policies

Over the last decades, this worrying environmental situation and increased public awareness mobilized many nations to take measures to reduce the negative impacts of climate change (Cifuentes-Faura, 2022). The European Union has been one of the most active in environmental protection by developing policies aimed at safeguarding the health and well-being of citizens and protecting natural resources (Cifuentes-Faura, 2022). Indeed, over time the European Union has demonstrated to have the highest environmental standards in the world through several developments and advances made in the field of environmental protection (Cifuentes-Faura, 2022). Even though the issue of climate change had been identified in the 19th century, it was not until the First World Climate Conference in 1979 that the topic was addressed on a worldwide scale. Following this, a series of international agreements and policies were adopted. In 1987 the Montreal Protocol was approved to protect the ozone layer. In 1988 the Intergovernmental Panel on Climate Change (IPCC) was established by the United Nations Environment Programme and the World Meteorological Organization. Since then, there have been extensive international discussions, known as the Conference of the Parties or COP, aimed at reaching a global agreement on emission reduction and environmental protection (Harris and Roach, 2017). In 1990 the IPCC published the first report which scientifically confirms the evidence of climate change (Cifuentes-Faura, 2022). Two years later in June 1992 Rio de Janeiro hosted the United Nations Conference on Environment and Development (UNCED), also known as the Rio Conference or the Earth Summit, which represented a major United Nations conference. It was created as a response for member states to cooperate on issues related to sustainability. The Rio Conference resulted in the creation of the United Nations Framework Convention on Climate Change (UNFCCC), an international environmental treaty to prevent human activities from damaging the climate system and to stabilize greenhouse gas concentrations in the atmosphere (Gupta, 2010). Moreover, at the Rio Conference, the Agenda 21, the Convention on Biological Diversity and the Rio Declaration on Environment and Development were adopted (Gupta, 2010). The first Conference of the Parties (COP1) was held in Berlin in 1995, where the participant countries agreed to commit to meeting once a year to monitor global warming and reduce greenhouse gas emissions (Cifuentes-Faura, 2022).

A key international environmental treaty is the Kyoto Protocol adopted in 1997 which commits state parties to reduce greenhouse gas emissions (Gupta, 2010). However, it proved difficult to ensure the ratification of Russia and Japan, which happened later in 2005. Another issue was the withdrawal of the US from the Protocol in 2001. The Kyoto Protocol does not include new long-term objectives, but it rather extends the ones of the 1992 United Nations Framework Convention on Climate Change (Gupta, 2010). Furthermore, the Kyoto Protocol includes five mechanisms: Joint Fulfilment, Joint Implementation (JI), the Clean Development Mechanism (CDM), Emissions Trading

(ET), and the financial mechanism to promote the implementation of the agreement. Another crucial international environmental treaty is the Paris Agreement, negotiated by 196 countries at the 2015 United Nations Climate Change Conference. On the contrary, it has the long-term goal of keeping the global temperature well below 2°C above pre-industrial levels and preferably limiting the increase to 1.5°C (Cifuentes-Faura, 2022). The Paris Agreement also provides for continuing financial and technical support to developing countries to help them adapt to the disruptive consequences of climate change. For this reason, the Agreement includes a loss-and-damage clause (Harris and Roach, 2017). Moreover, each party to the Paris Agreement is required to establish a Nationally Determined Contribution, which is a climate action plan to cut emissions, adapt to climate impacts and update it every five years. The European Union is committed to a binding target of reducing emissions by at least 40 per cent by 2030 compared to 1990, and it managed to reduce 19 per cent of greenhouse gas emissions (Harris and Roach, 2017). Indeed, the Climate Action Tracker, an independent organization which provides assessments and ratings of submitted NDCS, rated the European Union as a "medium" for its commitment. Whereas it rated as "inadequate" the commitments of a long list of countries, such as Russia, Japan, Australia, New Zealand, Canada, South Africa, and Chile (Harris and Roach, 2017).

The United Nations Conference of the Parties at Glasgow (COP26) in 2021 represented an important turning point because the participating countries committed to taking further action to tackle climate change and help vulnerable nations (Cifuentes-Faura, 2022). The main goals were to gradually decrease coal use globally and to encourage developed countries to double their aid to developing nations in order to assist them in adapting to climate change (Cifuentes-Faura, 2022).

Besides the commitment to the abovementioned agreements, the European Commission approved in 2020 the European Green Deal to make the European Union climate-neutral in 2050. This plan aims to finance the circular economy, building renovation, biodiversity, farming, a sustainable food system, and innovation (Cifuentes-Faura, 2022). Moreover, the Green Deal proposes several targets to reduce CO2 emissions from the transport sector. Indeed, emission rights will be applied to road transportation by 2026, putting a price on pollution, promoting cleaner fuels, and stimulating investment in clean technology. The European Commission proposes to extend carbon pricing for the aviation and maritime sectors as well (Cifuentes-Faura, 2022).

The promotion of the circular economy is another goal set by the European Union to increase sustainability, produce less waste, and make circularity work for people, regions, and cities in the EU. Indeed, in 2019 the European Union created the first Action Plan for the Circular Economy which consists of producing sustainable goods the standard in the EU, ensuring that the latter last longer on the market, and are simpler to reuse and recycle. Furthermore, this plan focuses on resource-intensive industries with a high potential for circularity, including ICT and electronics, batteries, packaging, plastics, textiles, construction and building materials, water, and nutrients (Cifuentes-Faura, 2022).

To sum up, the European Union has been a primary force behind environmental advancement in many of the abovementioned developments. The introduction of the European Green Deal demonstrated the EU's steady effort and gave new impetus to climate change policy (Cifuentes-Faura, 2022).

1.5.2 Carbon Tax

The concept of the carbon tax was introduced by the British economist Pigou in the early 1920s, based on the idea that if the environmental and social costs are not included in the price of activities they generate, then the government might determine their value by the appropriate taxation (Hájek et al., 2019). The authors Hájek et al. (2019) specify that there are three possibilities of carbon taxation. The first one is the fuel tax which corresponds to the amount of carbon generated by burning a specific fuel. The second one is the CO2 tax which charges the amount of carbon dioxide emissions. Finally, the third one is the energy tax that puts a price on fossil fuels as the first one but covers nuclear and renewable energy sources. The CO2 tax is the most cost-effective one since it reflects the environmental costs in the prices of final products (Hájek et al., 2019). Thus, a carbon tax should lead to a reduction in power consumption and carbon emissions, and an incentive to use renewable resources and invest in clean technologies (Hájek et al., 2019). Moreover, it creates revenues that the government could use to achieve further environmental benefits and reduce government borrowing or debt and other inefficiencies in the economy (Elkins and Baker, 2002).

To test the environmental effectiveness of a carbon tax, the authors Elkins and Baker (2002) used the following equation, if the effects of the tax fall on producers:

$$CO2 = (CO2/E) * (E/ES) * (ES/I) * (I/O) * O$$

E stands for energy inputs, *ES* for energy services (heat, light, power), *I* input to production, and *O* stands for output. The tax will tend to reduce the producers' profits and output (*O*). Thus, to counteract this effect, producers will seek to reduce their CO2 emissions by reducing the other terms of the equation as well. By doing so, they will tend to switch to less carbon-intensive fuels (reducing *CO2/ES*), use energy more efficiently in the production processes (reducing *E/ES*), and reduce their demand for energy services relative to other production inputs (reducing ES/I). Moreover, they will seek to develop new technologies for future production processes which reduce all these ratios (Elkins and Baker, 2002). On the other hand, if the tax falls on the consumers, the authors developed this equation:

$$CO2 = (CO2/E) * (E/ES) * (ES/EIGS) * (EIGS/CE) * CE$$

Here, the terms are the same as the above one, except for *EIGS* which stands for energy-intensive goods and services, and *CE* which means consumer expenditure. In this event, producers will try to switch to less-carbon-intensive fuels (reduce *CO2/E*), use energy more efficiently (reduce *E/ES*), and reduce both the proportion of energy services in energy-intensive goods and services (reduce *ES/EIGS*) and the share of *EIGS* (including *ES*) in consumer expenditure on all goods and services (reduce *EIGS/CE*) (Elkins and Baker, 2002).

Therefore, the environmental effectiveness of a carbon tax depends on the ease of switching to less carbon-intensive fuels, the opportunity to deliver energy services more efficiently, and the growth in demand for energy services, relative either to production inputs or energy-intensive goods and services (Elkins and Baker, 2002).

1.5.3 Cap and Trade

Finally, the cap-and-trade system combines a legal limit on the number of emissions with an incentive-based approach to allocating the emission reduction required to comply with this legal limit between firms and other actors (The Core, n.d.). The cap-and-trade policy starts with the government setting the cap, representing the total amount of greenhouse gases that can be emitted by the installations covered by the system. The cap is expressed in emission allowances, where one allowance gives the right to emit one tonne of CO2 equivalent (European Commission, n.d.). Then the government gives permits to the polluting firms. The latter may trade their permits with other firms because of an excess or scarce number of permits, depending on the amount of emissions emitted by each firm. Finally, the firms submit permits to the government to cover their emissions.

For each tonne of emissions produced, firms are asked to provide one permit to the government (The Core, n.d.).

One of the first cases of successful emissions trading was the sulphur dioxide (SO2) cap and trade scheme introduced in the US in the 1990s to reduce acid rain. By 2007, annual SO2 emissions had fallen 43 per cent from 1990s levels. In the European Union by the end of 2000, the details of a cap-and-trade scheme had not been fully worked out yet. Although at the time only Denmark's government introduced a carbon emissions trading scheme for the Danish power sector. This sector emitted around 40 per cent of Denmark's CO2 emissions, and the scheme intended to contribute to a 21 per cent emissions reduction (Elkins and Baker, 2002).

1.5.3.1 European Union Emissions Trading System (EU ETS)

In 2005 the European Union launched the largest CO2 cap-and-trade in the world: the European Union Emissions Trading System (EU ETS). It covers 30 member states and over 11,500 polluting installations from the electricity, combustion, coke, iron, steel, cement, lime, glass, ceramics, brick, tile, refinery, paper and pulp across Europe, accounting for 40 per cent of total greenhouse gas emissions (Venmans, 2012). The EU ETS has been divided into four phases: the first phase or trial period (2005-2007), the second phase (2008-2012), the third phase (2013-2020), and the fourth and ongoing phase (2021-2030).

The EU ETS is a conventional cap-and-trade system, but at the same time, it presents some significant design differences from other cap-and-trade schemes implemented in the US (Ellerman and Joskow, 2008). The first difference is the decentralized nature of the EU ETS cap. Indeed, there was not an initially determined overall limit, but the member states were responsible for proposing several allowances, subject to review and approval by the European Commission following the procedures and criteria specified in the EU Emissions Trading Directive (Ellerman and Joskow, 2008). According to Ellerman and Joskow (2008), another difference of the EU ETS is that is "a cap within a cap from 2008 on". This means that the Kyoto Protocol sets a cap on greenhouse gas emissions across the entire economy. The EU ETS includes only CO2 emissions and only a specific category of the economy, namely the power sector, some industrial sectors, and "all combustion facilities with a thermal input of greater than 20 MW regardless of the sector in which they are found" (Ellerman and Joskow, 2008). The greenhouse gas emissions from sources not included in the EU ETS, notably transportation and buildings, are limited by other policies and measures. However, the Emissions Trading Directive, already in the first phase, anticipates the inclusion of other GHGs and other activities in an expanded EU ETS in the following periods and a proposal to include CO2 emissions from aviation beginning in 2011 (Ellerman and Joskow, 2008).

The decentralized character of the EU ETS is not limited to cap-setting. Indeed, it extends to almost all aspects of the system, from the distribution of allowances, and the operation of the registries for tracking allowances and emissions, to the monitoring, reporting, and verification procedures. It can be said that the EU ETS represents 27 largely independent trading systems which agreed to trade their allowances and adhere to certain criteria and procedures, established by the European Commission, to make this system work (Ellerman and Joskow, 2008). This process starts with the development of a National Allocation Plan (NAP), in which member states propose the total number of allowances for the trading period, give a list of covered installations, and explain the distribution of allowances (Ellerman and Joskow, 2008). Moreover, each member state has its registry to record the creation, transfer, and surrender of allowances. The transfer of EUAs among installations is also reported to a central registry in Brussels, namely the Community Independent Transaction Log (CITL). Thanks to this means, any member state that is not in compliance with the EU ETS or does not receive approval for its National Allocation Plan might have transfers from that state blocked by the Commission (Ellerman and Joskow, 2008). Finally, member states also develop their monitoring, reporting, and verification procedures subject to the EU Monitoring and Reporting Guidelines (Ellerman and Joskow, 2008).

The allocation of allowances is at the heart of the EU ETS, but it also represents its Achilles heel. Indeed, the method of allocation of allowances can compromise the success of the trading phase. The two most discussed options are the auction by the government and the grandfathering of permits (Elkins and Baker, 2002). The former is the most transparent for allocating emission allowances and it follows the principle that the polluter should pay. In the case of the EU ETS, the auctioning of allowances is regulated by the Auctioning Regulation. To guarantee that auctions are held in an open, transparent, uniform, and non-discriminatory manner, the Auctioning Regulation addresses the scheduling, administration, and other aspects of the process. It stipulates that auctions must meet certain requirements, including predictability, cost-effectiveness, equitable access to auctions, and full access to all the information (European Commission, n.d.). Grandfathering, the second option, is the most popular choice, although it is unfair.

Permits are allocated for free based on emissions in the recent past. Indeed, large emitters are faced with new regulations but obtain large amounts of free permits in return. An example of this situation happened in 2012 when the aviation industry became part of the EU ETS and emission permits were grandfathered based on the emissions per airline in 2005 (Tol, 2014). The two big discount airlines, EasyJet and Ryanair grew rapidly between 2005 and 2012, whereas the three big incumbents, British Airways, Lufthansa, and Air France grew more slowly in this same period. The two discounters flew newer and more fuel-efficient planes. Moreover, they had a higher load factor, flew point-to-point, avoiding energy-intensive take-offs and landings, and avoided congested airports. By doing so, the discounters emitted less carbon dioxide than the incumbents. Nonetheless, the incumbents received relatively generous allocation permits, leading to a transfer of wealth from the discounters to the incumbents, without decreasing the amount of emissions (Tol, 2014). The main difference between these two methods is distributional. Auctions, such as the carbon tax, transfer resources from emitters to the government, generating revenues. On the other hand, grandfathering of emission permits seems to provide polluters with assets in the form of tradable property rights (Elkins and Baker, 2002). For this reason, emission permits should be auctioned by the government, rather than grandfathered. Indeed, governments can use revenues to reduce distortionary taxes and thus increase economic efficiency. Auctions can also spread both the costs of carbon control and the gain of permit allocation more equitably through the economy. Finally, as abovementioned, auctions give fair access to emission permits and avoid difficult decisions over allocation (Elkins and Baker, 2002).

Another significant feature of the EU ETS is the banking or borrowing of allowances between trading phases (Ellerman and Joskow, 2008). Although allowances are given out yearly, they can be used to cover emissions in any year during the trading period. Moreover, at the end of February each year's issuance of allowances occurs, precisely two months before allowances must be surrendered for the preceding year. Therefore, by issuing allowances for the following year, installations can cover shortages in any given year (Ellerman and Joskow, 2008). This setup essentially permits borrowing for the entire year ahead of time during the trading period. Despite this, banking and borrowing were not allowed between the first and second trading periods (Ellerman and Joskow, 2008). In Chapter 2 section 2.2 will be explained why.

1.5.4 Carbon Tax vs. Cap and Trade

Studies are focusing on the impacts of the two economic instruments for pollution pricing: the carbon tax and the cap-and-trade scheme. First, both approaches share similarities and important differences (Harris and Roach, 2017). They can both reduce pollution to a certain degree, by increasing at the same level the prices for final consumers. Moreover, they can both create incentives for technological innovation and generate the same amount of government revenues, assuming that all permits are auctioned off (Harris and Roach, 2017).

The advantages of a carbon tax include simpler understanding and more transparency since it can be implemented more quickly. Indeed, given the need to address climate change adversities as soon as possible, a carbon tax could be a better approach. Moreover, a carbon tax provides greater price predictability and stability, especially when there is uncertainty over the control of cost function because the carbon tax fixes the price (Harris and Roach, 2017; Elkins and Baker, 2002). On the other hand, a cap-and-trade system can be more complex and requires new bureaucratic institutions to operate. Furthermore, in the cap-and-trade system, there is a significant fluctuation in emission allowance prices, making planning more difficult. For instance, during the first phase of the EU ETS, the emission allowances were set too large and went far from the 20€ planned, not producing the desired effect of emissions reduction (Hájek et al., 2019). However, the cap-and-trade system presents many advantages. First, it avoids the negative connotation of a "tax", generating in this way less political opposition (Harris and Roach, 2017). Moreover, the biggest advantage of a cap-and-trade system is that emissions are known with certainty since the government sets the number of permits that can be issued. Indeed, the goal is to reduce carbon emissions; a carbon tax does this indirectly with a price raise, whereas a cap-and-trade scheme does so directly, through the achievement of a specific emissions path by setting the number of permits (Harris and Roach, 2017). Indeed, a cap-and-trade system is preferable when there is uncertainty about the damage function (Elkins and Baker, 2002).

Whether to choose a cap-and-trade system or a carbon tax primarily depends on how concerned policymakers are about emissions or price uncertainty. A carbon tax is preferable if they adopt the viewpoint that price stability is crucial because it enables better long-term planning. A cap-and-trade system is better if they think that the relevant policy objective is to reduce carbon emissions by a given amount, even though it might cause some price volatility (Harris and Roach, 2017).

To sum up, in this first chapter this dissertation presented the threats of climate change on the Earth's ecosystems and the lives of human beings. It attempted to show the importance of an economic perspective to understand better the dynamics behind climate change and in this way the possible solutions. Furthermore, this first chapter displayed the different options to combat climate change adopted through the years, by the European Union, which demonstrated great ability and steadiness to cope with this issue.

2. The Assessment of the European Union Emissions Trading System

In the following chapter, this dissertation will attempt to evaluate the European Union Emissions Trading System (EU ETS) effectiveness by phase. This evaluation will be based on how this cap-and-trade scheme was successful in reducing CO_2 emissions, whether it affected the economic performance, considering the profit and the competitiveness of the EU ETS firms.

2.1 The Preparation of the EU ETS

The authors Ellerman and Joskow (2008) provide a detailed description of the preparation of the EU ETS. A few years following the Kyoto Protocol's negotiation, it was acknowledged that a more aggressive mitigation action was needed to meet the EU's Kyoto commitments. Thus, because it guaranteed a limit on a substantial portion of the EU's emissions, was compatible with the Kyoto Protocol's emissions trading provisions, and was the only alternative instrument available, a cap-and-trade approach was chosen (Ellerman and Joskow, 2008). This measure was first proposed as a component of the European Climate Change Programme in a Green Paper in March 2000 (Ellerman and Joskow, 2008). This concept paper outlined the fundamentals of the cap-and-trade mechanism, identified the critical problems to be solved, and addressed the general elements of designing an EU CO_2 trading system. However, it took until October 2001, just three years before the program was set to launch, for a clear and detailed implementing directive to be proposed (Ellerman and Joskow, 2008). It was only in July 2003 that the Council of Ministers gave its final approval, and the Emission Trading Directive was formally issued in October of the same year (Ellerman and Joskow, 2008). Moreover, the Directive implemented and approved the National Allocation Plans at the end of March 2004. Indeed, the Directive provided the guidelines for the allocation process. At the same time, the Member States decided on the total national allocation of emissions allowances to be allocated to the installations included in their National Allocation Plans (Kettner et al., 2010). 95 per cent of the EUAs during the first phase were allocated for free following the installations' historical emissions, with the allocation method of grandfathering. Moreover, the emissions cap was fixed at 2,298 $MtCO_2$ per year (Dechezleprêtre et al., 2018).

This short-time implementation spread scepticism among economists and policymakers. An editorial in Point Carbon published in September 2001 stated that there was a low-probability scenario that the trading scheme would have been in place by 2005

(Ellerman and Joskow, 2008). Despite the initial disbelief and complicated implementation, the performance of the EU ETS in the first phase should be evaluated considering that it constituted a “trial” phase, a warm-up to build the necessary experience to ensure the successful use of this measure and the reduction of CO2 emissions. Moreover, although the EU ETS was inspired by the Kyoto Protocol, it was also independent of it. Indeed, it was passed before the Kyoto Protocol became enforceable under the international and European law. Thus, the first phase served as a means also to ensure the EU’s compliance with the Kyoto Protocol from the second phase onward (Ellerman and Joskow, 2008).

2.2 Phase 1 (2005-2007)

This subsection will evaluate the first phase of the EU ETS from 2005 to 2007. First of all, it is important to analyse the price evolution during this phase since it varied significantly with a price collapse that occurred in April 2006. This was due to an excess supply of allowances because too many permits were freely grandfathered, and emissions reduction was much easier and cheaper to realize than expected. Moreover, deviations from expected emission levels reduced demand for EUAs to the point where prices collapsed (Anderson and Di Maria, 2011). The following subsections will examine the price trend and the allocation of allowances of Phase 1, to understand why abatement was lower than expected.

2.2.1 Price Trend

Ellerman and Joskow (2008) provide a useful graphic (Figure 2.1) to better understand the price trend during Phase 1 since January 1st, 2005, when the EU ETS went into effect. The two series of prices shown in the figure below represent the first and the second periods. Each of these is a different product because banking between phases was not allowed in Phases 1 and 2 (Ellerman and Joskow, 2008). Considering the issues that occurred in Phase 1, this rule was a way to self-contain this phase, preventing any failures from extending into the second trading phase and complicating the EU’s commitments under the Kyoto Protocol (Ellerman and Joskow, 2008).

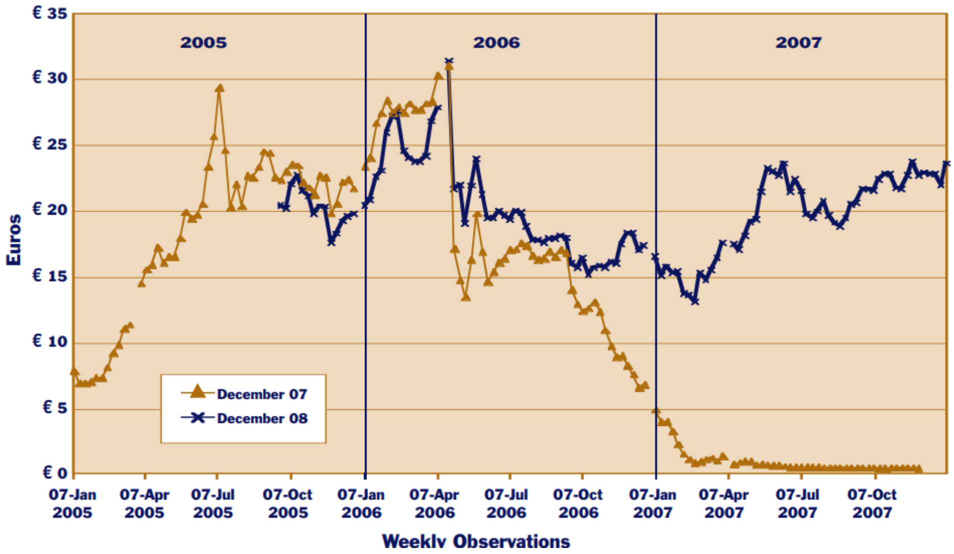

Figure 2.1 Evolution of EUA Prices (2005-2007) (Ellerman and Joskow, 2008)

In the few months after the launch of the EU ETS, prices, which had previously been roughly €10/tCO2, rose to surprisingly high levels (Grubb and Neuhoff, 2006). This was due to three main factors. In Spring of 2005, the European Commission cut the proposed national caps of the Czech Republic and Poland by 54 and 141 million tonnes respectively which caused EUA prices to rise to €20 by the end of May 2005. Moreover, oil and gas prices increased, leading electricity production back to coal and raising the CO2 price to 30€ at the beginning of July 2005 (Grubb and Neuhoff, 2006). In addition, prices increased up to 35 € due to a cold late winter and a dry summer in southern Europe in early 2005 (Ellerman and Joskow, 2008). When in the last week of April 2006 data on verified emissions of the first trading year became available, it was clear that the EU ETS market was long, meaning that an unexpected surplus of allowances occurred (Ellerman and Joskow, 2008). As a consequence, prices fell to 12€ within one week (Kettner et al., 2010). This sharp break reflects a phenomenon very common in the cap-and-trade system: initial expectations about prices are often wrong (Ellerman and Joskow, 2008). In the first period of this scheme, the problem was not the cap, which was known from the beginning, but the expected aggregate emissions, which determined the actual demand for allowances. Along with the usual unpredictable variables of weather, energy prices, and economic activity, this uncertainty also reflects, possibly more importantly, the amount of abatement that will occur in response to the new price on emissions (Ellerman and Joskow, 2008). Despite this, prices increased to 20€ again in the summer of 2006, because of a shortage in allowances in the power sector. In the autumn of the same year, prices started to decline again until the end of 2007 (Kettner et al., 2010).

2.2.2 The Allocation of Allowances

As mentioned in Chapter 1, the allocation of allowances is a key feature of the EU ETS, but in Phase 1 this represented an obstacle to the achievement of CO2 emissions abatement.

The authors Kettner et al. (2010) report an analysis of the EU ETS in the first phase based on the database from the Community Independent Transaction Log (CITL). This analysis was performed on three indicators: the total of all EU member states, the individual member states, and a cross-country selection of emission-intensive sectors. Moreover, they used other four indicators to calculate the stringency of the caps of the first phase: the gross short and long positions and the net long and short positions. These indicators are better explained by the authors Anderson and Di Maria (2011). The gross long totals correspond to "the sum of the differences between allocated and verified emissions for installations where the number of allocated permits was greater than verified emissions". In contrast, the gross short totals correspond to the insufficient allocation of emissions to cover verified emissions. Finally, the net short and net long positions are the difference between the two (Anderson and Di Maria, 2011). As displayed in Figure 2.2, during the first three years of the EU ETS on average 2,145 million tonnes per annum were allocated, but only 2,077 million tonnes were verified (Kettner et al., 2010).

This reflects the market's long position with 69 million tonnes of EUAs, corresponding to 3.2 per cent of allocated allowances. Moreover, this net long position is the result of balancing a 186 million tonnes (8.7 per cent) gross short position, the proportion of allowances below verified emissions, with a 256 million tonnes (11.9 per cent) gross long position, or the relative amount of allowances allocated to installations above their verified emissions (Kettner et al., 2010). This means that overall verified emissions were well below the cap set in Phase 1, meaning that an over-allocation of allowances has occurred (Grubb et al., 2012). As indicated in Figure 2.2, the UK, Austria, Ireland, Italy, and Spain are the five out of 24 countries that were in a short position up to -17.6 per cent, in the case of the UK representing the extreme of this category (Kettner et al., 2010). This means that these countries were under-allocated and needed to buy permits from over-allocated countries to cover their emissions levels (Anderson and Di Maria, 2011). Unfortunately, these countries were disproportionately present and the companies having long positions were not as active in the market (Ellerman and Joskow, 2008). On the other hand, the remaining 19 counties were long up to 44.8 per cent, with Lithuania representing the other extreme of this category (Kettner et al., 2010).

The authors Ellerman and Buchner (2008) and Anderson and Di Maria (2011) report similar results to Kettner et al.'s (2011), with Lithuania and the UK representing the extremes of over-allocation and under-allocation respectively.

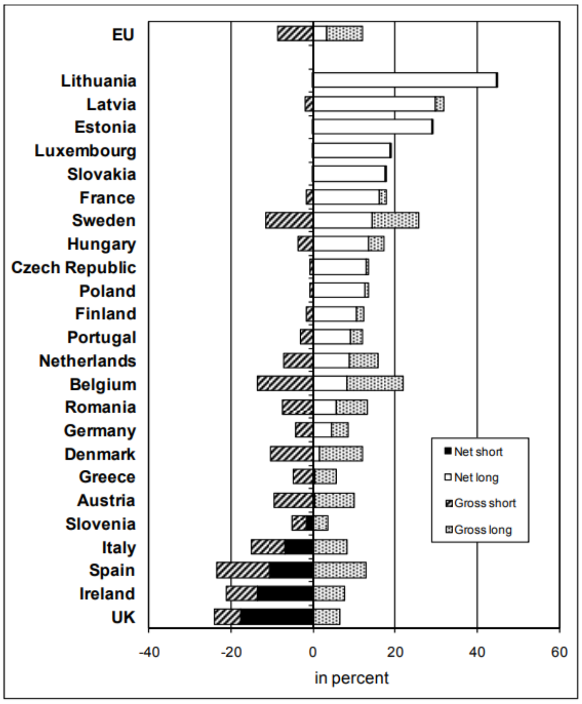

Figure 2.2 Short and Long Positions by Countries (2005-2007) (Kettner et al., 2010)

Moreover, Kettner et al. (2010) analysed participant sectors' long and short positions in the EU ETS. Figure 2.3 illustrates a pronounced long position up to more than 20 per cent for all sectors, with cement and lime and iron and steel sectors accounting for approximately 10 per cent of EUAs. In contrast, power and heat were in a short position. These sectoral differences were motivated by competitiveness concerns. Indeed, sectors more exposed to international competition were in long positions with over-allocation of allowances. Among them were refineries, iron and steel, cement, glass, lime, ceramics, pulp, and paper. On the other hand, the power and heat sectors were less exposed to international competition and thus received fewer allowances (Kettner et al., 2010). Moreover, this decision was made because the power and heat sectors' abatement potential were larger than in the other sectors (Kettner et al., 2010). The ability of EUAs to pass on additional costs due to their market power might be another factor contributing to the under-allocation of the heat and power sectors (Kettner et al., 2010).

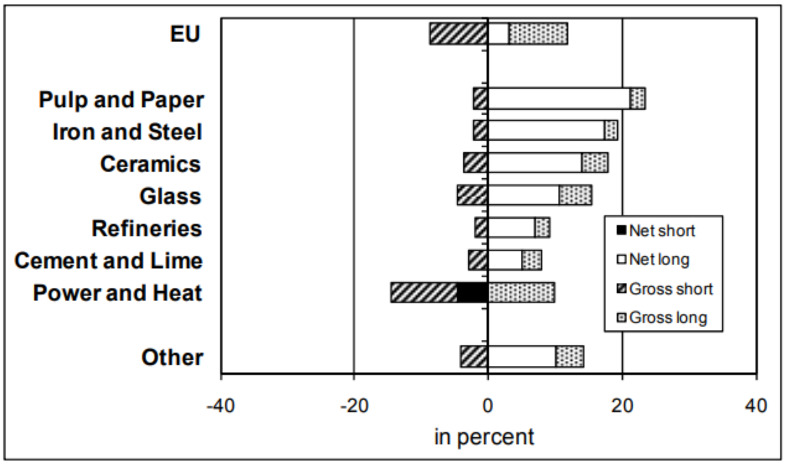

Figure 2.3 Short and Long Position by Sectors (2005-2007) (Kettner et al., 2010)

To conclude, during Phase 1 a wide dispersion of allocation discrepancies occurred. Indeed, installations with smaller amounts of emissions had a higher dispersion of the allocation discrepancy in contrast to big installations. Indeed, the latter often expressed concern about the unequal treatment in the allocation method of different member states. Consequently, during this first trading period, smaller installations were in long positions, while bigger installations were in short positions (Kettner et al., 2010).

2.2.3 Emissions Reduction

In light of all these data, the abovementioned authors reached a common result. The first trading period achieved a low level of abatement. Dechezleprêtre et al. (2018) find that the emission reduction observed in Phase 1 was only -6 per cent. Anderson and Di Maria (2011) conclude that there was a net abatement of 84.2, 61.7 and 27.6 MtCO2 in 2005, 2006, and 2007 respectively. Overall, according to the two authors, between 130-200 MtCO2 were abated during Phase 1. Grubb et al. (2012) report that emissions in the first phase increased slightly, from 2014 to 2055 MtCO2, corresponding to a 2 per cent increase. Abrell et al. (2011) found an increase in emissions as well, precisely 0.82 per cent. This was due to the cap set well below verified emissions, leading to a surplus of allowances that generally did not encourage companies to cut their CO2 emissions. Figure 2.4 from Dechezleprêtre et al. (2018) pictures this concept.

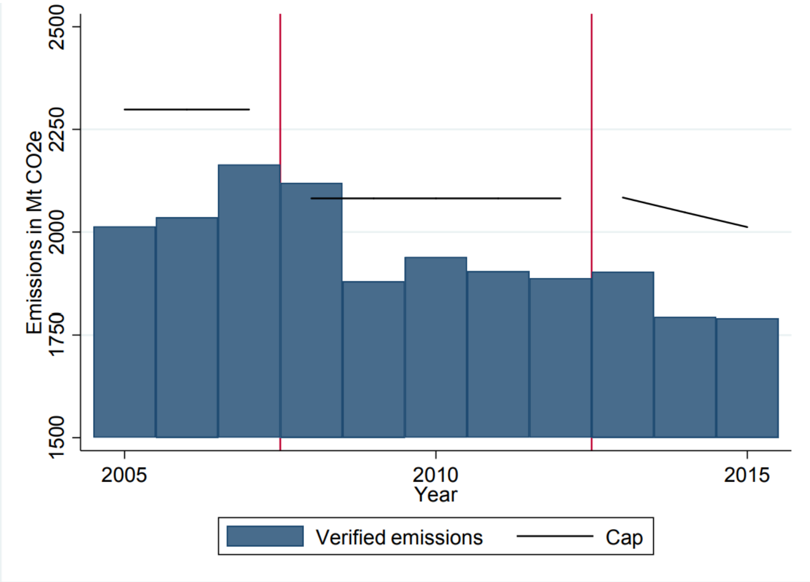

Figure 2.4 Overall Cap and Verified Emissions from EU ETS Installations 2005-2015 (Dechezleprêtre et al., 2018)

Kettner et al. (2010) confirm this theory, concluding that abatement played a minor role in determining the final net position of countries and state that:

> "It is rather unlikely that the EU ETS has already created incentives for abatement investments in the first trading years. Given the rather low carbon prices, it is also extremely unlikely that industries with a heavy CO2 cost component, such as cement and lime, have reduced their production levels because of the stringency of allowances" (Kettner et al., 2010).

In contrast, Ellerman and Buchner (2008) are more sympathetic. They argue that the amount of emission reduction may be modest, but so was the ambition of the 1st-period cap. They reach this conclusion for three main reasons. Firstly, this good level of abatement was due to a significant price paid for CO2 in 2005-2006 which reduced emissions. Secondly, the output was raised in the EU. Lastly, the comparison with historical emissions proved a reduction in emissions. Figure 2.5 illustrates in the first column the historical baseline, in the second column the average annual allocations, and in the third one the verified emissions for all the EU member states, namely EU23. The other two categories are the EU15 and EU8. The latter corresponds to the East European countries (Ellerman and Buchner, 2008). Thus, it can be observed that the verified emissions are 3.1 per cent less than the BAU emissions for the EU23, 2 per cent for the EU15, and 7.7 per cent for the EU8. Overall, the two authors find a level of abatement in the range of 120-300 MtCO2 in Phase 1 (Ellerman and Buchner, 2008).

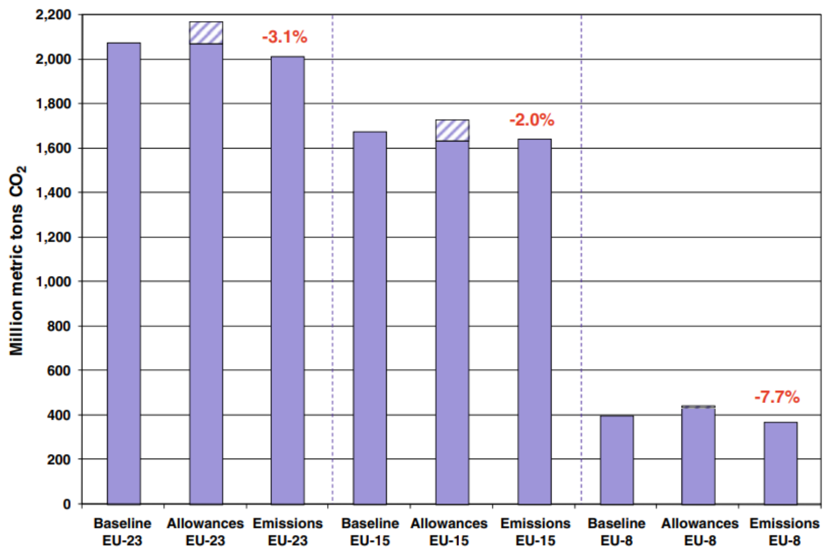

Figure 2.5 Comparison Between BAU Emissions and Phase 1 Verified Emissions (Ellerman and Buchner, 2008)

2.2.4 Impact on Economic Performance

Although the first trading phase reached a small level of CO2 abatement, profit and competitiveness were slightly affected by the EU ETS.

In terms of profit, the most carbon-intensive sectors, including fertilizers, iron and steel, aluminium, and paper experienced some positive effects. Indeed, these sectors did not see a large increase in marginal costs due to a combination of generous free allocation of allowances and low carbon prices (Dechezleprêtre et al., 2018). The economic theory argues that when too many free emissions allowances are given away, they can be sold for a profit in the market, and thus the phenomenon of windfall profits occurs (Carbon Market Watch, 2016). This has drawn heavy criticism and damages to the EU ETS public perception because the windfall profits implied issues with the distribution of economic surpluses among producers and consumers, and between sectors regulated by the scheme (Laing et al., 2012). Indeed, in the power sector, regulated firms experienced an increase in production costs by 5 per cent during Phase 1, associated with purchasing allowances due to their under-allocation, and/or substituting low-cost coal with more expensive fuel such as natural gas to mitigate emissions (Chan et al., 2013). However, power companies can recoup most of the cost of EU permits by increasing electricity prices, albeit not completely (Muûls et al., 2016). These pass-on costs affected the electricity consumers through higher prices. For this reason, the EU ETS during the first phase created winners and losers. The latter were exactly the consumers, both industrial and residential (Laing et al., 2012). However, it is noteworthy to say that the main purpose of the free allocation of emissions allowances in Phase 1 was to obtain the political support of large emitters and thus ensured that the introduction of the EU ETS did not reduce their profitability (Sijm et al. 2006).

In Table 2.1, Smale et al. (2006) sum the pattern of impact between sectors under the EU ETS, in terms of emissions, production output, and profits before interest, tax, depreciation, and amortization (EBITDA).

Sector	Emissions		Physical production output		EBITDA	
Allowance price scenario	Euro 15/tCO_2	Euro 30/tCO_2	Euro 15/tCO_2	Euro 30/tCO_2	Euro 15/tCO_2	Euro 30/tCO_2
Cement	–12	–14	–1.2	–4.4	13	25
Newsprint	–4	–4	–0.2	+0.68	9	15
Petroleum	–0.4	–0.7	–0.2	–0.7	0.4	0.6
Steel	–14	–21	–2.1	–10.6	12	18
Aluminium	–100	–100	–100	–100	–100	–100

Table 2.1 Effects of the EU ETS on Emissions, Production Output, and EBITDA (Smale et al., 2006)

As mentioned, the steel and cement sectors were largely affected in terms of profit. Prices rose in the cement sector because the EU ETS applied to 90–95 per cent of the products, and thus firms passed costs on to consumers. The same process occurred in the other carbon-intensive sector, the steel industry, in which the EU ETS applied to 80 per cent of the products, leading the steel manufacturers to pass 65 per cent of their marginal cost increases to the consumers (Smale et al., 2006). At the same time in these sectors, a reduction in output occurred (Smale et al., 2006). The petroleum sector was only very marginally affected, showing a little reduction in emissions due to its low emission intensity and very little opportunity for abatement (Smale et al., 2006). In contrast, the aluminium industry displayed a stark difference from the other sectors due to its global nature of competition, and thus even a small change in cost had a significant impact (Smale et al., 2006). In the one case of newsprint, a sector with medium energy intensity, the EU ETS helped the investment in clean technology and thus the impacts on output were positive, because a reduction in the marginal cost of production occurred, resulting from improved energy efficiency. (Smale et al., 2006). Indeed, investment intensity was generally positively influenced by the EU ETS of about 1.26 per cent (Marin et al., 2018). At the employment level, the introduction of the EU ETS negatively affected the regulated firms by about 2 per cent (Marin et al., 2018). Indeed, within this group, there was a substantial variation in the level of downsizing risk (Muûls et al., 2016).

2.2.5 Impact on Competitiveness

The EU ETS affected firms' competitiveness as well. Indeed, the economic theory argues that when companies participate in carbon trading, they put themselves at risk of losing market share to unregulated companies and global competitors. This pressure can eventually force them to move their production chains outside the EU ETS area of coverage (Muûls et al., 2016). This can lead to job losses and jeopardize the effectiveness of the scheme, as carbon emissions would "leak" outside Europe to unregulated countries. This phenomenon is called carbon leakage (Muûls et al., 2016). For this reason, companies with a higher risk of carbon leakage are given more free allowances (Elsworth et al., 2011).

Anger and Obernoderfer (2008) and Demailly and Quirion (2008) found that the competitiveness losses were small in Phase 1. Muûls et al.'s (2016) studies find a similar result with a small 0.9 per cent reduction in employment for regulated companies compared to unregulated ones. Moreover, Abrell et al. (2011) found another small but significant decrease in employment within the EU ETS. Smale et al. (2006) present a more detailed report of the EU ETS impact on competitiveness. As mentioned, steel and iron, cement and aluminium sectors were more exposed to adverse competitiveness implications under the EU ETS, due to their global nature of competition in the market, but the companies are in a stronger financial position as a result of the higher profits and somewhat lower output (Smale et al., 2006). Nevertheless, the sectors profited greatly when higher marginal costs were passed through to prices while they continued to receive mostly free allocations, but over time, this eventually resulted in a decline in the sectors' ability to compete globally (Grubb and Neuhoff, 2006). Indeed, passing through the opportunity cost increased prices relative to imports from regions outside the EU ETS, leading to a more competitive market with further increased input prices to compensate (Grubb and Neuhoff, 2006). Consequently, this allowed non-EU ETS companies to increase their output (Smale et al., 2006).

To conclude, the first trading period displayed some issues related to extreme inequality in the allocation of EU Allowances. This led to low levels of abatement because larger emitted were given more allocation. Indeed, these issues will be considered in the design of Phase 2, starting with a change in the method of allocation and a stricter emission cap.

2.3 Phase 2 (2008-2012)

In the second phase, the system went into effect to comply with the start of the first commitment period of the Kyoto Protocol, in which Member States had more concrete emission reduction targets to meet (Bordignon and Gamannossi degl'Innocenti, 2023). This phase was extended to include three more countries: Norway, Iceland, and Liechtenstein. The aviation sector was included as well (Bordignon and Gamannossi degl'Innocenti, 2023). Moreover, the EU recognized the use of international credits via mechanisms in the Kyoto Protocol, namely the Clean Development Mechanism (CDM), which issued the Certified Emissions Reductions (CERs) credits, and the Joint Implementation (JI), providing instead the Emission Reduction Units (ERUs) (Chevallier, 2010). Companies in the EU ETS can use these credits to meet a percentage of their emissions reduction targets. Indeed, the price of these credits is lower than the European Union Allowances, thus many firms are choosing to buy and surrender these offsets and bank the EUAs (Elsworth et al., 2011). In detail, developed nations that have committed to reducing their greenhouse gas emissions can choose to invest in projects that lower emissions in developing nations rather than incurring higher costs for reducing emissions within their borders thanks to the Clean Development Mechanism. Instead, through the Joint Implementation, developed nations can finance initiatives that lower emissions in other developed nations, helping them to fulfil a portion of their legal commitment to reduced greenhouse gas emissions (European Commission, n.d.).

The passage from Phase 1 to Phase 2 brought some improvements. The main one is the possibility of banking unused permits into future periods. The reduction of the cap on the amount of allowances represents another improvement of Phase 2 (Ahamada and Kirat, 2012). Indeed, the European Commission's revision decided on a reduction of 6.5 per cent decrease in emissions compared to the 2005 level (European Commission, n.d.). The allocation methods of EUAs slightly improved. Member States are allowed to auction up to 10 per cent of their allowances. Indeed, auctioning allowances is widely considered a recommended method of EUAs' allocation, despite in this phase it was more the exception than the rule (Hepburn et al., 2006). Hepburn et al. (2006) point out that auctioning allowances can provide several benefits, including an increase in environmental effectiveness since it decreases the number of free allowances. Furthermore, it improves the price stability because it reduces the risk of price spikes if certain allowances were kept in reserve and made available to the public only in the event that the price rose above a specific threshold for a set period of time (Hepburn et al., 2006). Moreover, auctioning raises revenues which can be reallocated to correct distributional impacts. For instance, auction revenues are employed to reduce general taxes (Hepburn et al., 2006).

2.3.1 Price Trend

In 2007 the ban on the bankability of permits between Phase 1 and Phase 2 led to a price collapse towards 0€, as can be seen in Figure 2.6 (Creti et al., 2011). As illustrated in Figure 2.7, during Phase 2 prices rose and oscillated between 10€ and 30€/ton of CO2, depending on the levels of allowances demand due to industrial production and the impact of the economic crisis in 2009 (Chevallier, 2010).

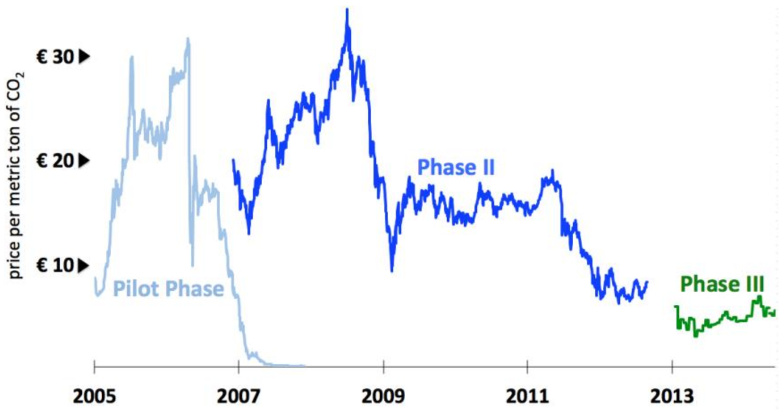

Figure 2.6 Price of EU ETS Allowances from Phase 1 to the Beginning of Phase 3 (Dechezleprêtre et al., 2018).

During the first months of Phase 2, spot prices fluctuated between €19 and €23 due to the shortness of allowances permitted, as illustrated in Figure 2.7 (Abrell et al., 2011). In April 2008 prices started to increase and peaked above 30€/ton of CO2 at the end of July 2008 (Creti et al., 2011). However, in the summer of 2008, the economy was hit by a severe crisis, namely the Great Recession. This caused a significant reduction in economic activity, and thus a reduction in electricity demand (Declercq et al., 2010). Consequently, a gradual decline in prices can be observed. This undervaluation can be related to the decline in permit prices that began in August 2008, coinciding with a decline in gas prices brought on by the drop in oil prices. This made gas, which is less polluting than coal, more appealing and consequently drove down the price of carbon (Creti et al., 2011). This situation was exacerbated by the economic crisis which further depressed the market prices, leading to a downward spike between February and

March 2009 which reached the lowest level in the considered period (Creti et al., 2011). In the spring of 2009, the price experienced a moderate recovery which lasted for about two years, at around 15€ (Creti et al., 2011).

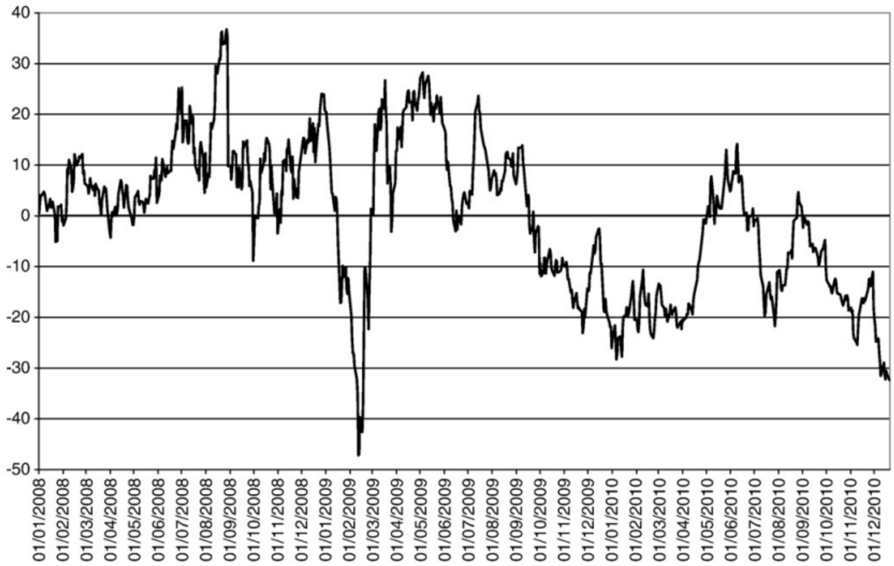

Figure 2.7 Price Trend in Phase 2 (2008-2010) (Creti et al., 2011)

However, the economic and policy environment of the EU ETS has substantially changed since 2011. Indeed, in the summer of this year, prices fell again by around 50 per cent to a new level of 7–8€ for 2012 before falling further to around 4€ with the start of Phase 3, as illustrated in Figure 2.6 (Koch et al., 2014). The authors Koch et al. (2014) report the three main causes that can explain the weak 2011 EUA prices. The first is the already mentioned deep and lasting economic crisis in the European Union. The second cause is related to overlapping policies. The third cause concerns the large influx of Certified Emission Reductions (CERs) and Emission Reduction Units (ERUs) in the EU ETS during Phase 2 (Koch et al., 2014).

As mentioned, the economic crisis reduced companies' production within the EU ETS, leading to a lower permit demand, but it was not the only factor (Koch et al., 2014). Indeed, in December 2008 the European Council adopted a new international agreement to reduce emissions of greenhouse gases. This included the so-called “three 20 targets”, namely the reduction of 20 per cent of greenhouse gas emissions compared to 1990 levels by 2020, the increase of 20 per cent of energy efficiency in the EU, and lastly the achievement of 20 per cent of renewables in total energy consumption in the EU (Wikipedia, 2023). Thus, to reach the 20-20-20 targets, the European Union launched generous support mechanisms to stimulate the development and deployment of renewable energy sources (RES). These include the electricity sector's hydro, wind, and solar capacity (Koch et al., 2014). As illustrated in Figure 2.8, the coexistence of EU ETS and RES deployment targets created a case of interaction effects. Indeed, the RES injections displaced CO2 emissions within the EU ETS, reducing the EUA demand and price (Koch et al., 2014). Moreover, the authors suggest that RES deployment reduced the EUA price by 46€ in 2008 and more than 100€ in 2010 (Koch et al., 2014).

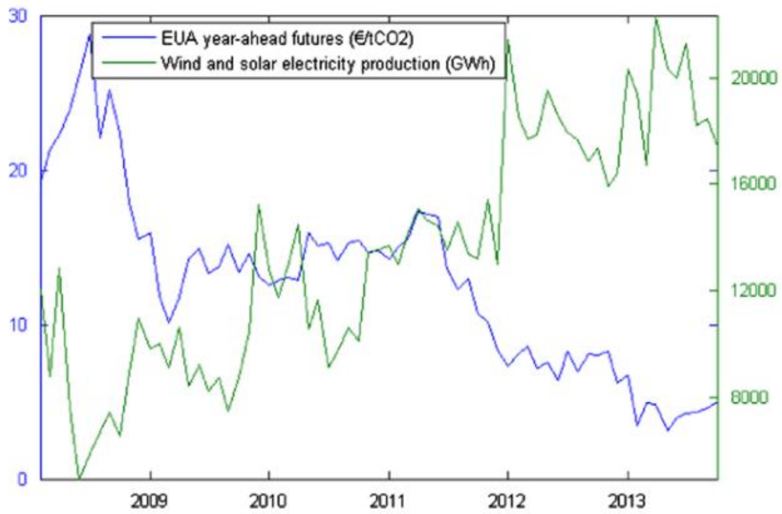

Figure 2.8 The Evolution of EU Allowance (EUA) Prices Jointly with the Deployment of Electricity from Renewable Energy Sources (Koch et al., 2014).

The other factor that reduced the EUA prices was the use of offset credits, CERs and ERUs, issued by the Kyoto Protocol. Indeed, their unexpectedly high use during Phase 2 contributed to a decreasing EUA demand and price (Koch et al., 2014). Over 60 per cent of the total allowable 2008–2020 quota had already been turned over by companies for compliance between 2008 and 2012, more specifically, 2011 and 2012 experienced a high use of Kyoto credits (Koch et al., 2014).

As much as the economic crisis, the overlapping policies, and the influx of CERs and EURs did affect the EU allowance price, the authors Koch et al. (2014) conclude that they were not the decisive factors. Indeed, these causes represent only 10 per cent of the drivers of price change. According to the authors, the remaining 90 per cent was unexplained (Koch et al., 2014).

2.3.2 The Allocation of Allowances

The number of allowances distributed decreased from Phase 1 to Phase 2 by approximately 11 per cent, leading to a 2 per cent decline in verified emissions (Abrell et al., 2011). Consequently, in 2008, companies were on average short of allowances. Thus, the verified emissions exceeded the allocated allowances by 2.9 per cent, as illustrated by the solid cyan line, representing the total verified emissions, above the allocated allowances line (dotted pink line) in Figure 2.9 (Abrell et al., 2011). However, according to Declercq et al. (2010), this net shortage of allowances was reduced to 115 Mton after the injection of EUAs through auctioning (Declercq et al., 2010). Furthermore, installations under EU ETS were allowed to surrender Certified Emission Reductions (CER) and Emission Reduction Units (ERU), issued from the two Kyoto Protocol projects, to comply with their verified emissions, as displayed by the dashed blue line. The injection of these credits amounted in 2008 to 82 Mton and 48 Kton, respectively, leading to a further reduction of the shortage of 33 Mton This remaining amount was borrowed from the 2009 allocation (Declercq et al., 2010).

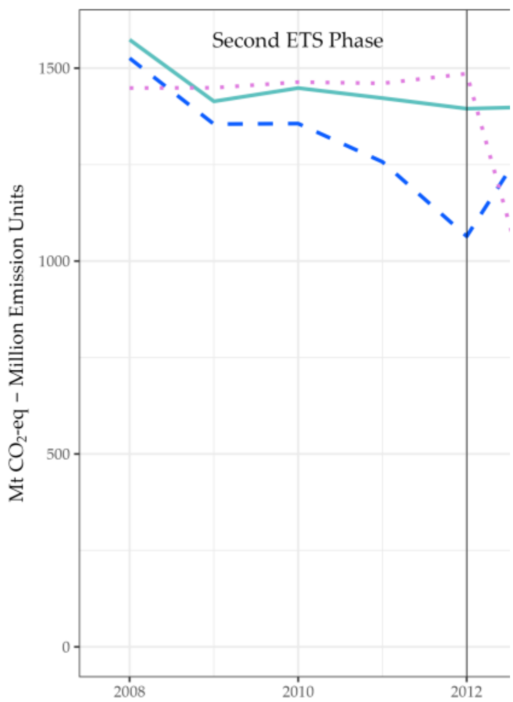

Figure 2.9 Dynamic of Total Verified Emissions, Surrendered Allowances and Allocated Allowance During Phase 2 of the EU ETS (Bordignon and Duccio Gamannossi degl'Innocenti, 2023).

The authors Kettner et al. (2010) report in Figure 2.10 to what extent this under-allocation affected the Member States.

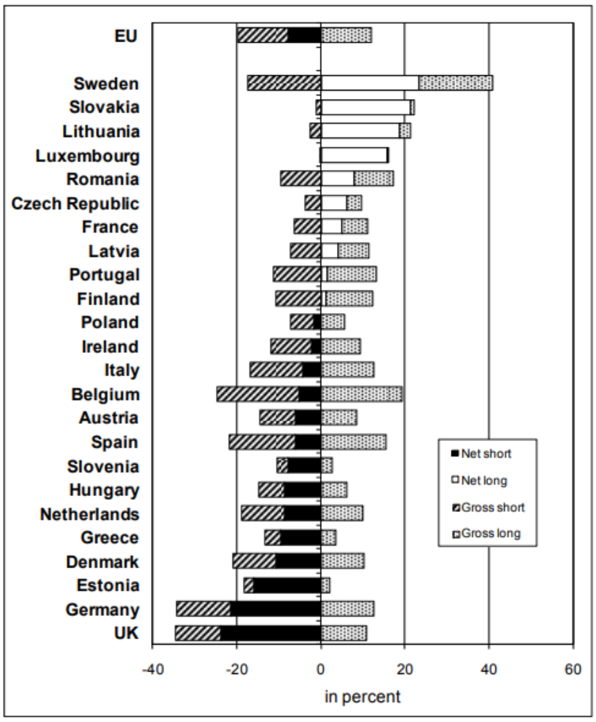

Figure 2.10 Short and Long Positions by Countries (2008) (Kettner et al., 2010)

Indeed, in contrast to Phase 1, the Baltic States displayed a reduction in net long positions. Lithuania's net long position decreased from 44.8 per cent to 18.7 per cent in 2008. Latvia's net long position fell from 29.8 per cent to 4.1 per cent. Moreover, Estonia's net long position changed into a net short position of 15.9 per cent. These results reflect that these countries faced the most severe cuts in allocation caps since Phase 2 experienced a reduction in free allowances (Kettner et al., 2010). Germany also experienced a change from a net-long position country in Phase 1 to the second-highest short position in Phase 2. The UK remained in the highest net short position from 17.6 per cent in Phase 1 to 23.8 per cent in 2008.

Regarding the allocation of allowances by sectors, cement, lime, iron, and steel, they have roughly remained constant as in Phase 1, thus displaying a net long position. Indeed, they shared between 240 million surplus allowances equivalent to the annual combined greenhouse gas emission of Austria (87M), Denmark (64M), Portugal (78M), and Latvia (12M) (Elsworth et al., 2011). Moreover, these heavy industry sectors were amongst the largest users of international offsets, both from international ETS, especially from India and China, and the credits generated by the two Kyoto Protocols projects, despite they already had a generous number of allowances (Elsworth et al., 2011). In contrast, the short position of the power and heat sectors was even more pronounced in

Phase 2, acting as the main buyer in the scheme (Elsworth et al., 2011). Refineries faced a more stringent cap in the second trading period as well.

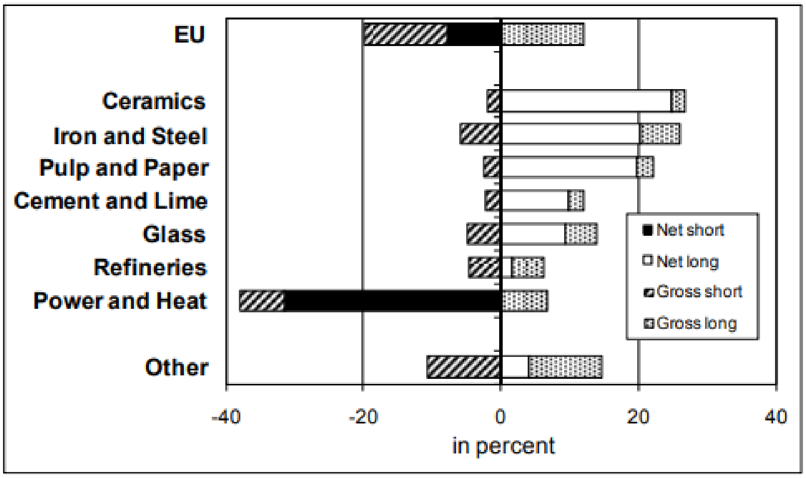

Figure 2.11 Short and Long Positions by Sectors (2008) (Kettner et al., 2010)

After the initial under-allocation of allowances, albeit reduced by the injection of auctioned allowances and the Kyoto Protocol projects' credits, from 2009 until the end of Phase 2 verified emissions went well below the allocated ones, displaying a sizeable over-allocation of allowances. This was mainly due to the reduced economic activity, which thus lowered the demand for allowances during the Great Recession (Bordignon and Duccio Gamannossi degl'Innocenti, 2023).

2.3.3 Emissions Reduction

As seen in the previous subsection, the financial crisis also affected the European companies within EU ETS, by reducing the demand for EU Allowances and energy. This led to a reduction in CO2 emissions as well (Laing et al., 2013). Data estimates that the year-on-year emissions reduction between 2008 and 2009 was the largest in the period (Laing et al., 2012). Indeed, as illustrated in Figure 2.12, in 2008 emissions from EU ETS sectors displayed a downward trend just below 2000 Mt CO2e. Moreover, the next year, 2009, experienced a large drop in emissions of almost 220 Mt CO2, while the EU economy was contracting by almost 5 per cent (Laing et al., 2012). Emissions climbed again in 2010 but remained at 9 per cent below 2005 levels (Laing et al., 2012).

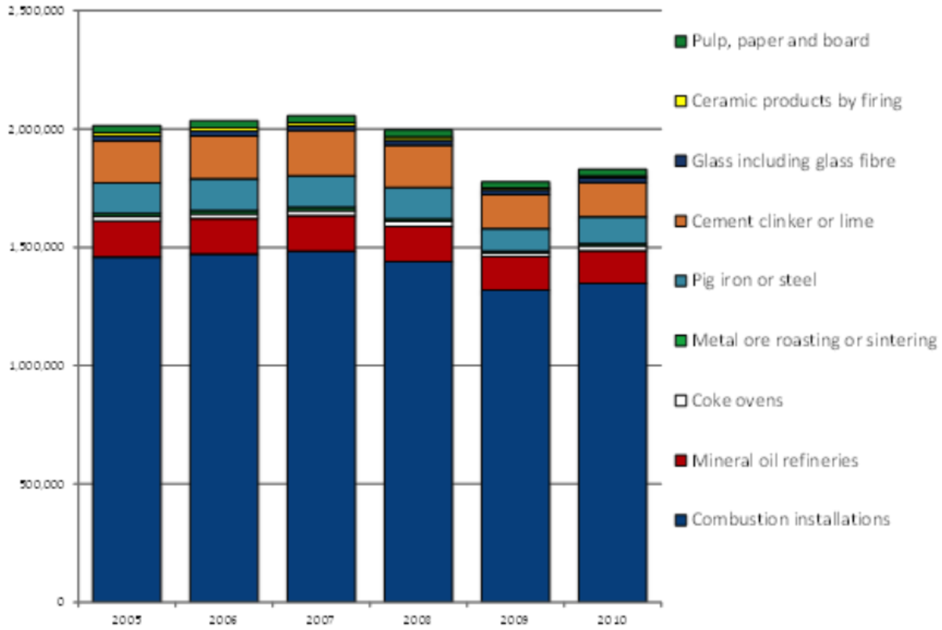

Figure 2.12 EU ETS Verified Emissions by Sector, Focusing on the 2008-2010 Period (Laing et al., 2012).

Among the Member States within the EU ETS, France, Netherlands, Norway, and the UK had a significant 15 per cent CO2 emissions reduction in Phase 2, compared to 6 per cent in Phase 1. On the other hand, Lithuanian firms saw little change in CO2 emissions in Phase 2, as well as Germany's with only a 2 per cent decrease (Bordignon and Duccio Gamannossi degl'Innocenti, 2023). Overall, CO2 emissions were reduced by 3.35 per cent on average in Phase 2 (Muûls et al., 2016).

Many scholars of this thesis bibliography agree that the emissions reduction in Phase 2 was attributed mainly to the economic crisis (Laing et al., 2012; Bordignon and Duccio Gamannossi degl'Innocenti, 2023; Koch et al., 2014; Declercq et al., 2010). However, according to Abrell et al. (2011), the emissions reduction was not only caused by the economic crisis, because this did not imply a proportionate loss in output for the companies within the EU ETS. Instead, it was due to some improvements that occurred from Phase 1 to Phase 2, namely the stringent cap of Phase 2 and the allocation method with fewer free allowances; the allowed bankability of permits to future phases; and since the long-term reduction target for 2020 was made public in 2008, the uncertainty regarding the availability of permits in the future during the second phase decreased (Abrell et al., 2011).

2.3.4 Impact on Economic Performance

As in Phase 1, profit and competitiveness were slightly affected by the EU ETS as well in Phase 2. Indeed, some positive effects were found on performance, investment, labour productivity, and turnover (Marin et al., 2018). The high cap set in Phase 2 resulted in low prices on the market for permits, thus reducing the cost of complying with the EU ETS, even for carbon-intensive industries. This led to some favourable conditions, for the power sector, which managed to pass through increased production costs to consumers, resulting in higher electricity prices, and for heavy industries thanks to an oversupply of free allowances (Marin et al., 2018).

Regarding the power sector, it experienced an increase in material costs by 8 per cent since it was even more under-allocated than in Phase 1. This might be associated also with the costs of complying with parallel renewable incentive programs, as mentioned in Subsection 2.3.1. However, this sector managed to recoup these costs by passing them to the consumers, resulting in a turnover increase of 30 per cent compared to Phase 1 (Muûls et al., 2016; Chan et al., 2013). In contrast, steel and iron, refineries, and cement sectors were given a surplus of allowances, resulting in 19 European countries making over €24 billion in windfall profits in Phase 2 (Carbon Market Watch, 2016). Windfall profits were made in three different ways. The first one was due to the allowance's surplus, and thus companies were able to sell their surplus for a profit in the market, making 8.1€ billion. In the second way, heavy industries made 0.6€ billion from offsets, because they sold their remaining free allowances for a profit on the market. In the third and last way, windfall profits came from cost-pass through, making 15.3€ billion. Indeed, these companies generated profits by letting their customers pay the price for freely obtained emission allowances (Carbon Market Watch, 2016). Among the heavy industries, the cement sector was able to generate the most money by receiving too many free allowances and selling this surplus for profits on the market (Carbon Market Watch, 2016).

In contrast to Phase 1, there was no negative effect on employment (Marin et al., 2018). Indeed, the concerns about job losses after the first trading phase of the EU ETS were overestimated, especially due to an unexpectedly low price of emission allowances. Wages were not affected either, demonstrating their rigidity in EU member states, and the negligible impacts of the EU ETS on the labour force (Marin et al., 2018). As in Phase 1, investment intensity was positively affected by the EU ETS, with an increase of 1.56 per cent (Marin et al., 2018). Moreover, there was another positive impact on labour productivity, corresponding to an increase of around 5 per cent (Marin et al., 2018).

2.3.5 Impact on Competitiveness

As mentioned, heavy industries within the EU ETS were the most exposed to international competition, thus receiving a surplus of free allowances and international credits. These companies received international offsets mostly from rival firms, but this did not prevent the former from sending money to the latter in return for their credits (Elsworth et al., 2011). Furthermore, iron and steel productions are widely perceived as being most at risk of carbon leakage. As a result, installations were issued generous free allocations from Member State governments to reduce the burden of a carbon price on industry and keep them internationally competitive (Elsworth et al., 2011). To put these data into perspective, Figure 2.13 compares the EUA surplus of all heavy industries, named by the authors Elsworth et al. (2011) “Fat Cats”, and ArcelorMittal, the biggest multinational steel manufacturing corporation, to the 2008 annual GHG emissions of some of Europe’s largest member states (Elsworth et al., 2011). As of 2010, the accumulated EUAs for all heavy industries are already larger than the emissions of Belgium and the Netherlands put together. Moreover, by itself, ArcelorMittal’s surplus overtook Belgium’s annual emissions.

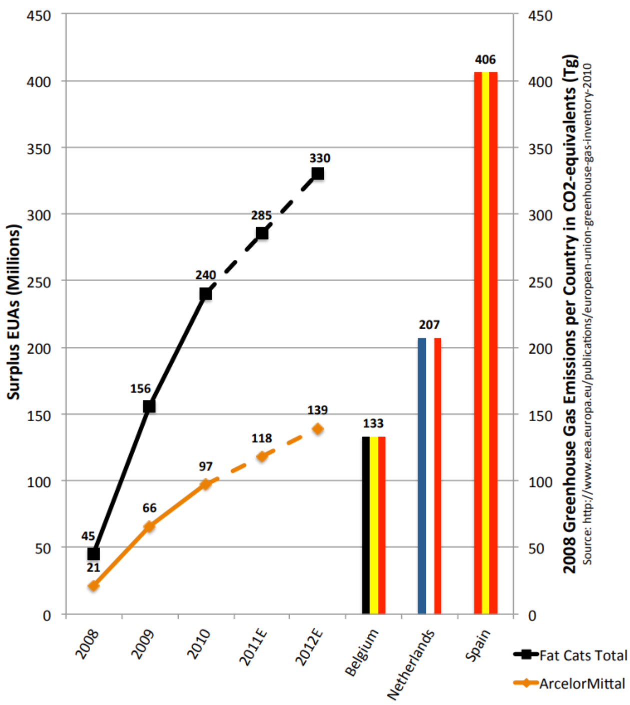

Figure 2.13 Comparison Between Some EU Member States, Fat Cats, and ArcelorMittal’s EU Allowances (Elsworth et al., 2011).

To conclude, Phase 2 reached a greater CO2 abatement level than Phase 1, mostly due to the Great Recession which reduced Europe's economic activity, but also to some improvements in this phase, including a reduced cap and a smaller amount of free allowances and a 10 per cent of auctioned allowances. Despite this slight advancement, over-allocated heavy industries still profited through windfall profits. However, with Phase 3 there would be a greater change in the allocation method, with the auctioning that would become more a rule than the exception.

2.4 Phase 3 (2013-2020)

The third trading phase of the EU ETS was widely considered more effective in reducing emissions due to a series of reforms (Bordignon and Gamannossi degl'Innocenti, 2023). First, a new country joined the scheme, Croatia, as well as other new sectors, including aluminium, mineral insulation wool, petrochemicals, ammonia, nitric, adipic and glyoxylic acid production, CO2 capture, transport in pipelines, and geological storage of CO2 (Bordignon and Gamannossi degl'Innocenti, 2023).

The first improvement was the introduction of a stricter and EU-wide cap set at 2084 Gton for 2013, and the implementation of the Linear Reduction Factor (LRF). It consisted of the rule that in 2014 and each subsequent year of Phase 3 till 2020, the cap decreased linearly by 1,74 per cent of the number of allowances (Bordignon and Gamannossi degl'Innocenti, 2023). Freely allocated allowances underwent a stark reduction, with only 43 per cent allowed. More importantly, power generation installations could no longer receive free allowances and 100 per cent auctioning was implemented. However, electricity-generating installations in lower-income Member States, including Bulgaria, Croatia, Czechia, Lithuania, Estonia, Latvia, Hungary, Poland, Romania, and Slovakia, could receive free allowances to support investment for the contribution of diversification of the energy mix, restructure, and implementation of clean technologies. Furthermore, auctioning for industrial installations was instead increased from 20 per cent in 2013 to 70 per cent in 2020, with a target of 100 per cent for 2030 (Bordignon and Gamannossi degl'Innocenti, 2023). It is worth saying that the allocation of free allowances was also used to prevent these emission-intensive and internationally competitive industries from relocating to unregulated countries and risking carbon leakage (Bordignon and Gamannossi degl'Innocenti, 2023). Moreover, the free allocation of EUA had the goal of achieving emission reduction targets, but also of fostering investment in energy-efficient technology. For this reason, the benchmarking approach, which is based on the lowest GHG emitters in each production process, has taken the place of the grandfathering allocation method, which was based on historical emissions (Bordignon and Gamannossi degl'Innocenti, 2023). In this way, the least polluting companies were fully granted free allowances, while the others had to buy EUA for their excess emissions. Indeed, the benchmark method had the double goal to minimise the national-level distortions in the allocation of allowances, and to encourage countries to search for more efficient ways to improve their environmental performance (Bordignon and Gamannossi degl'Innocenti, 2023). Furthermore, the use of credits from the Kyoto Protocol projects was limited to about 300 additional credits, compared to the 1.3 billion limits of Phase 2 (Ellerman et al., 2015).

Among the reforms in Phase 3, in November 2012, the European Commission published a report with six alternatives for "reconstructing" the EU ETS (Ellerman et al., 2015). They included the increase in the EU reduction target to 30 per cent in 2020; the retirement of allowances in Phase 3; the reduction of 1.74 per cent annually of the cap as mentioned; the goal to cover other sectors; the limit of access to international credits; and the creation of discretionary price management, such as the set of a price floor (Ellerman et al., 2015). This report was followed in March 2013 by a green paper on a 2030 framework for climate and energy policies, which discussed the post-2020 targets for renewable energy and energy efficiency, and the coordination of the EU ETS targets (Ellerman et al., 2015). Another significant event in Phase 3 was the entered into force of the Paris Agreement in December 2015. It is considered a landmark in the multilateral climate change process because it was the first time that a binding agreement brought all nations together to combat climate change and adapt to its effects (Carbon Tracker Initiative, 2018).

2.4.1 The Allocation of Allowances

Phase 3 began with a considerable amount of EUAs due to the surplus generated by the Great Recession, the impact of renewable policies, and the use of CERs and ERUs from Phase 2. Consequently, this surplus of allowances depressed the price, discouraging investment in energy efficiency technologies (Burns, 2017). Thus, the European Commission sought to hinder this trend for Phase 3 by implementing two reforms: the Back-loading and the Market Stability Reserve (MSR) (Burns, 2017). The Back-loading reform was created from a need of the European Commission to re-balance the supply and demand of allowances to increase the market confidence in the EU ETS (Burns, 2017). Thus, the Commission proposed to withdraw 900 million allowances from auctioning in 2014-2016, thus 400 million in 2014, 300 million in 2016, 200 million in 2016, and to add them back into auctioning in 2019-2020 (Burns, 2017; Ellerman et al., 2015). The second reform was the Market Stability Reserve, introduced in January 2014 by the European Commission in conjunction with the publication of a framework for climate and energy policy in 2030, and ultimately adopted in 2015 (Burns, 2017). The Market Stability Reserve's goal was to adjust the quantity of supply of emission allowances generated by the scheme, by limiting their total within a pre-defined range of 400 million to 833 million allowances (Burns, 2017). When there were more than 883 million allowances in circulation, 12 per cent of them were withdrawn annually and placed in the reserve (Burns, 2017).

These reforms and the shifting to auctioning and benchmarking significantly contributed to the reduction of free allowances and thus the effectiveness of the EU ETS (Lecourt et al., 2013). Indeed, the aggregate decline in free allocation was about 20.6 per cent on average over Phase 3, with some countries experiencing a fall in free allowances between -30 to -47 per cent (Lecourt et al., 2013). Countries that received a surplus of allowances in the previous phases witnessed more significant cuts.

As illustrated in Figure 2.14, the dotted pink line represents the allocation of free allowances that plummeted from the first year of Phase 3. Consequently, purchased EUAs increased considerably, due to both stricter enforcement with a rise in surrendered allowances and the reduction of free allocation (Bordignon and Gamannossi degl'Innocenti, 2023).

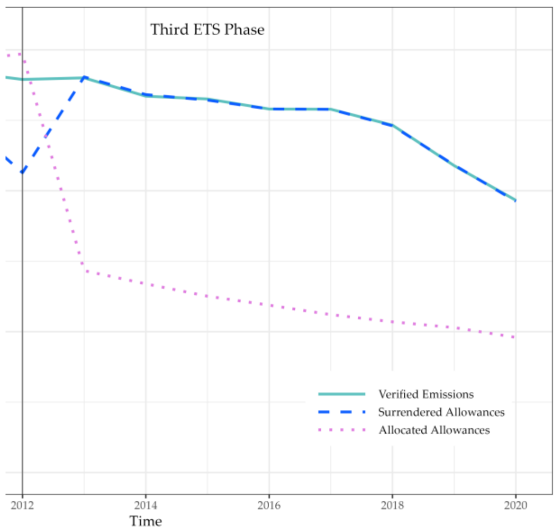

Figure 2.14 Dynamic of Total Verified Emissions, Surrendered Allowances and Allocated Allowance During Phase 3 of the EU ETS (Bordignon and Duccio Gamannossi degl'Innocenti, 2023).

2.4.2 Price Trend

Figure 2.6 shows that as Phase 3 began, prices fell by 50 per cent to around 3€. In contrast to what happened in 2007, the price did not fall to zero because allowances could be banked for use from Phase 2 to Phase 3 (Ellerman et al., 2015). However, as illustrated in Figure 2.15, in this phase prices stayed relatively low, ranging between 3.4 Euro/tCO2e and 9.6 Euro/tCO2e (Ghazani and Jafari, 2021). The most significant price variation was recorded in December 2015 with the entered into force of the Paris Agreement, resulting in a slight price increase. Nonetheless, following that, the EUA prices decreased monthly by approximately 43 per cent, reaching 4.98 Euro/tCO2e in February 2016 from a level of 8.67 Euro/tCO2e in November 2015 (Ghazani and Jafari, 2021). This trend changed after April 2017 when prices rose from 4.9 Euro/tCO2e to 8.15 Euro/tCO2e in about nine months. (Ghazani and Jafari, 2021). Between January and September 2018 prices spiked above 25 Euro/tCO2e.

Figure 2.15 Price Trend in Phase 3 (Bulai et al., 2021)

Starting from January 2020, prices fell again due to the major shock brought by the COVID-19 pandemic. Indeed, global economic activity suddenly halted in the first half of 2020, resulting in a decrease in energy demand (Gerlagh et al., 2020). By the end of April 2020, European energy demand fell by 11 per cent, and demand for emission allowances decreased along with lower emissions, and EUA prices. From January to May 2020, the price decreased by around 20 per cent compared to 2019 but rose again by June 2020 (Gerlagh et al., 2020). The COVID-19 pandemic led to global economic shock, carrying severe recessions for many countries, but EUA prices did not fall at the same level as during the economic crisis in 2009 (Ghazani and Jafari, 2021). This is mostly due to the introduction of the Market Stability Reserve (Gerlagh et al., 2020). Indeed, it managed to stabilize the market. By effectively cancelling EUAs in the MSR, which cannot return to the market, the cumulative cap on emissions was reduced and the cumulative supply of EUAs became endogenous (Gerlagh et al., 2020).

2.4.3 Emissions Reduction

As seen in the previous subsections, emissions reduction in Phase 3 was greater than the other two phases, due to a series of reforms within the EU ETS scheme and at the European level, and to the economic recession brought by the COVID-19 pandemic. According to Burns (2017), among the Phase 3 reforms, the Linear Reduction Factor was the one that appeared entirely attributable to the significant decline in emissions. Overall, the total emission reduction was 422 MtCO2-eq, corresponding to a reduction of 26 per cent from 2005 levels (Bordignon and Gamannossi degl'Innocenti, 2023; Burns, 2017).

2.4.4 Impact on Economic Performance

Data relative to the impact on economic performance and competitiveness for firms within the EU ETS in Phase 3 were scarce. The little that was found saw a slight decrease in output, especially during 2019 and 2018 when the price of allowances increased (Bordignon and Gamannossi degl'Innocenti, 2023). Employment was another factor that was negatively affected in Phase 3. Consequently, productivity and output per employee increased (Ellerman et al., 2015). Overall, there was no sign of adverse effects on economic performance (Bordignon and Gamannossi degl'Innocenti, 2023).

2.4.5 Impact on Competitiveness

As mentioned, heavy industries were the most exposed to carbon leakage. As in Phase 1 and 2, the aluminium sector was at risk because the share of extra-EU imports compared to domestic production increased. Concerning the cement sector, the risk of carbon leakage slightly decreased in Phase 3 (Healy et al., 2018). This might be thanks to benchmarking which reduced the differences in free allocation and thus possible competitiveness distortions (Lecourt et al., 2013).

To conclude, Phase 3 displayed a greater CO_2 emissions reduction thanks to the improvement of the EU ETS system with the introduction of the Market Stability Reserve, the benchmarking, and a bigger percentage of auctioned allowances. Furthermore, Phase 3 was more successful also due to the reforms to combat climate change at the European level, including the Paris Agreement.

2.5 Phase 4 (2021-2030)

Phase 4 is ongoing, and thus there is no sufficient data to assess it wholly. The CO_2 emissions reduction data are only available until 2021, whereas there are no data available yet to assess the EU ETS under the economic performance and competitiveness of the firms.

Phase 4 was officially completed in 2018, with a new sector joining the scheme, the maritime division. This consisted of all emissions from boats docking in EU harbours from intra-EU voyages and 50 per cent of emissions from non-EU international trips (*ETS-Phase 4 in a Glimpse*, 2022). However, in July 2021, the European Commission implemented the European Green Deal which updated the 2030 climate targets. For example, this policy reform aimed at reducing greenhouse gas emissions by 55 per cent compared to 1990 levels, a minimum renewable energy share of 32 per cent, and at least a 32.5 per cent improvement in energy efficiency compared to projections of the expected energy use (Bordignon and Gamannossi degl'Innocenti, 2023). Consequently, the EU ETS had to make significant changes to meet these new targets, including an increase in the level of emission reductions to be achieved by 2030 to 62 per cent below 2005 levels, the Linear Reduction Factor was reduced to 4.3 per cent for the period 2024-2027 and to 4.4 per cent for the period 2028-2030 (ETS-Phase 4 in a Glimpse, 2022). Furthermore, the cap will be tightened in two steps: in 2024 by 90 million allowances and in 2026 by 27 million (EU Emissions Trading System, 2022). Moreover, a share of auctioned revenues supplied two funds in Phase 4 to support decarbonization in the EU ETS. The first one is the Innovation Fund whose aim is to support highly innovative projects on low-carbon technologies and bring to the market novel decarbonization processes (Bordignon and Gamannossi degl'Innocenti, 2023). Modernisation Fund is the second one and supports investments and transitioning in low-carbon technologies in ten lower-income Member States, including Bulgaria, Croatia, Czechia, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, and Slovakia (Bordignon and Gamannossi degl'Innocenti, 2023).

As of Phase 4, the use of international offsets is not allowed anymore.

2.5.1 The Allocation of Allowances

The implementation of the "European Green Deal" affected the allocation of allowances in Phase 4. Indeed, the Market Stability Reserve's parameters were modified and reinforced. The Total Number of Allowances in Circulation (TNAC) was introduced as a pre-defined threshold. When the TNAC is above 833 million allowances, 24 per cent of them are withdrawn for future auctions and placed in the MSR for 12 months. Moreover, if a member state adopts additional policy actions that lead to the closure of electricity generation capacity, they can decide to cancel allowances from their auction share (EU Emissions Trading System, 2022).

As in Phase 3, allowances in the power sector are 100 per cent auctioned, with a derogation for the above-mentioned lower-income countries to grant free allocation (EU Emissions Trading System, 2022). Only Bulgaria, Hungary, and Romania took advantage of this opportunity. Czechia, Croatia, Lithuania, Romania, and Slovakia chose to transfer some of their allocations to the Modernization Fund. Finally, Estonia, Latvia, and Poland chose to auction their allowances instead (Bordignon and Gamannossi degl'Innocenti, 2023). Concerning industrial installations, benchmark values will be updated twice in Phase 4 to avoid windfall profits and reflect technological progress in different sectors. The first set will be applied for the period 2021-2025, and the second one for the period 2026-2030. The values will be adjusted according to changes in firms' industrial production.

Furthermore, the European Commission implemented the Carbon Border Adjustment Mechanism (CBAM), a tariff on imports of carbon-intensive goods from abroad, to mitigate the risks of carbon leakage (EU Emissions Trading System, 2021). Importers in sectors covered by CBAM, including cement, aluminium, iron and steel, fertilisers, electricity, and hydrogen, need to buy CBAM certificates. Then they need to declare the emissions included in their imports and surrender the corresponding number of certificates to ensure that the carbon price of imports is equivalent to the carbon price of domestic production (Carbon Border Adjustment Mechanism, 2023). The introduction of this tariff was aligned with the phase-out of the allocation of free allowances for these industries in the period from 2026 to 2034. In Phase 4 there will be a gradual phase-out of free allowances in the aviation sector as well in this same period (EU Emissions Trading System, 2022). Furthermore, the European Commission will decide how many free allocations for non-CBAM sectors are phased out during the benchmark exercise (EU Emissions Trading System, 2021).

2.5.2 Price Trend

Phase 3 ended with the major price shock brought by the COVID-19 pandemic, but the post-pandemic economic rebound increased CO2 emissions, and thus the demand for allowances (European carbon price at an all-time high, 2023). As illustrated in Figure 2.16, prices peaked, reaching the highest value of 100€/tonne in February 2023. In 2022, the Ukraine-Russia conflict drove gas prices higher and forced trade-offs in favour of coal (*European carbon price at an all-time high*, 2023). This price trend was due to Europe's reliance on Russian gas. Indeed, Russia is responsible for around 45 per cent of the EU's gas imports, and almost 40 per cent of its gas consumption. Consequently, the sanctions imposed on Russia after the war break limited the gas trade and froze individuals' and companies' assets (*How the Ukraine conflict is affecting the EU ETS carbon market*, 2022). This conflict revealed how weak the European energy security is. Thus, the International Energy Agency (IEA) published a 10-point plan to reduce the EU's imports of Russia's gas by at least one-third. These measures seemed in part effective since prices peaked (*How the Ukraine conflict is affecting the EU ETS carbon market*, 2022).

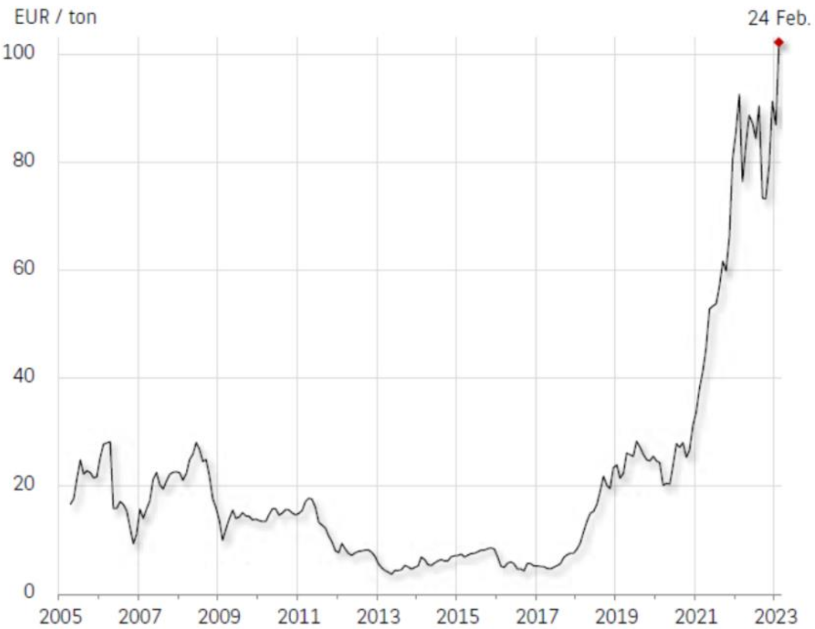

Figure 2.16 Price Trend in Phase 4 (European carbon price at an all-time high, 2023).

However, this price increase was related to many factors. First, it was due to the introduction of the Market Stability Reserve, which allowed a surplus of allowances to be stored, instead of reallocated in the market. Furthermore, the reforms of Phase 4 pushed the prices even higher with the tighter cap and phase-out of free allowances (*European carbon price at an all-time high*, 2023). The economic recovery after the COVID-19 pandemic contributed to an increase the energy demand as well (Bjørnland et al., 2023).

2.5.3 Emissions Reduction

As of 2021, the EU ETS reduced emissions by 46 per cent. It is worth saying that the COVID-19 crisis at the beginning of 2020 contributed to a massive drop in economic activity, reducing emissions enormously (Bjørnland et al., 2023).

In conclusion, the new mechanisms of the EU ETS seem successful in accelerating decarbonisation, especially if EUA prices keep staying this high.

2.6 Overall Evaluation of the EU ETS

The European Union's Emissions Trading Scheme is by far the most extensive and longest-running ETS in the world, and regardless of whether the program can overall be considered effective and successful in achieving its goals, there remain several lessons, insights, and information that can be taken away from it. Indeed, Phase 1 was filled with lessons to be learned due to issues with an over-allocation of allowances, a low and volatile price of carbon, the occurrence of windfall profits, and a low level of emissions abatement. Among these lessons, the National Allocation Plan represented the most important because it proved to be the main cause behind many of the issues in Phase 1 and Phase 2. Indeed, a clear link between the NAP and the issue of over-allocation of allowances in some countries was found. This surplus resulted in a low carbon price throughout the first two phases, which most likely did not help to encourage an increase in investment in low emissions technology. Furthermore, and most importantly, the over-allocation of allowances did not lead to a significant level of CO2 emission abatement.

Price volatility was perceived worst in Phase 2, primarily due to the economic recession which saw the price swing between 30€ per Mt in July 2008 and 4€ right at the beginning of Phase 3. This lesson was about the need for a price stabilization mechanism, realized by the Market Stability Reserve starting from Phase 3. Through this mechanism, the EU ETS could more easily ensure a less volatile price for emissions in the future.

Moreover, windfall profits represented a significant issue within Phases 1 and 2. They occurred in part due to not enough restrictions and/or support around the price of carbon through the EU ETS. In part due to the high-cost pass-through rates and massive profits from the sale of overallocated firms.

In Phase 2 another important lesson regarding the oversupply of allowances and price instability was learned. The move toward a higher number of auctioned allowances respected the principle of cap-and-trade theory in that the polluter should pay for their emissions directly, rather than being allocated a significant degree of allowances for free. The change in the allocation method toward auctioning and away from free allocation helped encourage a higher price for allowances, less of a possibility for windfall profits to occur, and hold the potential for an increase in low carbon investment due to increased revenue for the member states. Furthermore, the introduction of the Market Stability Reserve and this gradual decrease in free allowances lowered the risk of carbon leakage as well.

The complete ban on the use of the offset credits from the two Kyoto Protocol projects, namely the Clean Development Mechanism and the Joint Implementation, in Phase 4 was another lesson learned. Already in Phase 3 the use of these credits was limited, but in the current phase are completely banned due to concerns regarding their equitability, viability, and accountability. Indeed, these credits lowered the demand for EUA and decreased the price. Furthermore, together with the generous number of free allowances led to windfall profits, especially in heavy industries.

Overall, Phase 1 can be considered a learning phase, with a series of mistakes that were brought to Phase 2 as well. Instead, Phase 3 represented a course-correcting phase in that emissions abatement was higher, and there were positive changes regarding investment and the allocation method. Furthermore, windfall profits did not occur, as well as any discernible impacts on competitiveness. Phase 4 seems to have learned from past mistakes and it is trying to achieve the 2030 emissions reduction targets through the implementation of new measures. These improvements are reflected in the progressive trends of CO2 emissions reduction and EUA prices in Figure 2.17. However, some external events, including the 2008 economic crisis and the 2020 COVID-19 pandemic contributed to this emissions reduction as well. The price trend improved a lot from Phase 1 to Phase 4, from oscillating between 10€/t CO2 to almost 100€/tCO2.

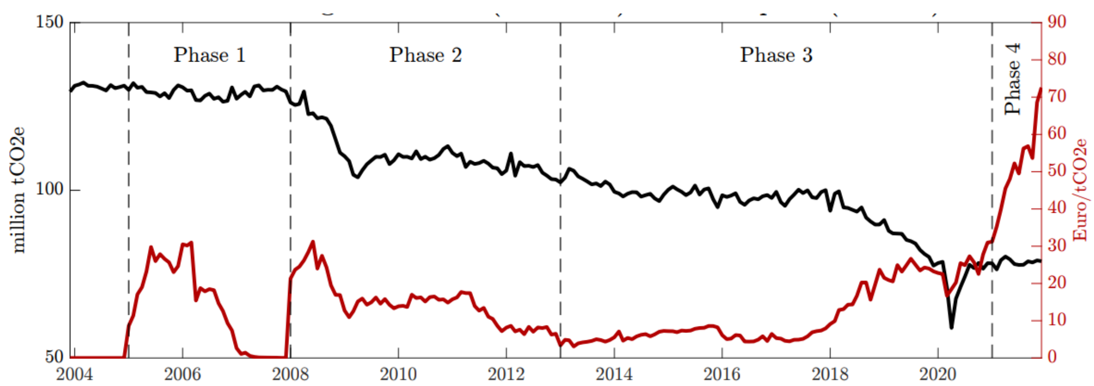

Figure 2.17 Greenhouse Gas Emissions (Black Line) and EUA Price (Red Line) Through All EU ETS Phases (Bjørnland et al., 2023).

3. Development of a Demand Function Equation to Prove the Importance of Including Methane Emissions Along the Supply Chain of Natural Gas and Crude Oil

This last chapter focuses on the need to include the entire supply chain emissions, namely upstream and midstream, and other greenhouse gases, particularly methane in the EU ETS. To illustrate this issue, the power sector, which uses crude oil and natural gas as inputs to produce energy, will be taken as an example. The first section displays the current challenges of the European Union Emissions Trading System. Then to introduce the topic of the chapter, the method for the calculation and price of the CO2 emissions in the power sector is explained. The following section describes the upstream and midstream supply chains of natural gas and crude oil and the related issue of flared, vented, and fugitive emissions. Following this, Section 3.8 describes and counts the fugitive emissions from the Algerian natural gas and crude oil supply chains to Italy. These results are used to develop the demand function, which will show how the choice of the Italian energy industry will eventually change after introducing the supply chain emissions, and whether the EU ETS is effective in reducing GHG emissions. The final section of the chapter provides some suggestions to improve the EU ETS and concludes. This dissertation aims to prove that the methane emissions along the supply chain of fossil fuels should be included in the EU ETS.

3.1 The Current Challenges of the European Union Emissions Trading System (EU ETS)

The European Union Emissions Trading System (EU ETS) represents a pivotal market-based instrument for greenhouse gas emission reductions for 30 European countries (Cammeo and Ferrari, 2022). Since the first trading phase, the scheme overcame many challenges to ensure its success in reducing GHG emissions and reaching carbon neutrality in Europe. Indeed, as of Phase 4, the EU ETS has little resemblance to its starting point of the National Allocation Plan, with 95 per cent of free allowances almost all grandfathered, no mechanisms to ensure an adequate and stable price and a high risk of carbon leakage (Ferrari, 2023). Currently, after several reforms, the cap has been set to decrease even faster over time, and the target for greenhouse gas emissions reduction has been increased from 43 per cent to 62 per cent by 2030 in the sectors covered by the system, compared to 2005 (Ferrari, 2023). Furthermore, the Linear Reduction Factor nearly doubles from 2.2 per cent to 4.3 per cent in 2024 and 4.4 per cent in 2028 until the end of Phase IV (Ferrari, 2023). However, what might seem still uncertain is whether these last improvements of the EU ETS will be enough to achieve these goals (Ferrari, 2023). Indeed, several critical design challenges remain (Sato et al., 2022). First, the EU ETS does not seem to have had much effect on investments in low-carbon capital and technologies (Sato et al., 2022). This might be due to the ongoing issue of unpredictable CO2 prices and rapidly changing rules which prevent sectors' investments in new low-carbon technologies in the long term (Sato et al., 2022). Indeed, one possible solution to overcome the volatility of CO2 prices could be making the European industry more resilient to price shocks (Dąbrowski, 2022). Most shortcomings of the EU ETS happened during the price crisis. The Market Stability Reserve was indeed designed to absorb the oversupply of the allowances from the market and release the allowances in case of scarcity. However, this mechanism is not based on the price of allowances but on the total number of allowances in circulation (TNAC). This means that when price shocks occur, the MSR does not react, like the recent one due to the Russia-Ukraine war, "especially if it assumes that the supply of allowances is about right" (Dąbrowski, 2022). The newly included maritime sector in the EU ETS represents another challenge. Indeed, it has been difficult to regulate because some parts of the legislation are yet to be enacted and decisions on who will be responsible for paying the charges remain unclear (Savvides, 2023).

Among the several current issues, this dissertation focuses only on a specific one: the need to include the upstream and midstream supply chains or indirect emissions in the system and other greenhouse gas emissions, especially methane. The current EU ETS includes only the direct or downstream emissions of the regulated firms, which correspond to the emissions from sources owned or controlled by the reporting firms (EPA, 2023). Introducing the upstream and midstream supply chain emissions in the system might instead offer a legitimate means to accelerate decarbonisation (Monciatti et al., 2021). To prove this point, this dissertation develops a demand function model in which a firm in the energy sector uses two inputs to produce energy: natural gas and crude oil. Once the firm enters the EU ETS, the two inputs' direct and indirect CH4 emissions will be calculated. This model wants to demonstrate how indirect emissions, especially methane, contribute to global warming, and thus tracking and pricing them would make the EU ETS more efficient in achieving its environmental goals and reaching decarbonisation.

3.2 Direct Emissions in the Energy Sector in the EU ETS

3.2.1 CO2 Direct Emissions

In the EU ETS, the energy sector includes fossil-fuelled power generation plants with an installed capacity of 20 MW or more. These fossil fuel plants burn significant quantities of coal, oil, or gas to create heat, which generates steam to drive turbines and thus generate electricity (World Nuclear Association, 2017). This dissertation will focus only on crude oil and natural gas. When burned, these fossil fuels produce large amounts of greenhouse gas emissions, especially CO2 and CH4. Once a firm in the energy sector enters the EU ETS, its CO2 is calculated through the emission factors. The Intergovernmental Panel on Climate Change (IPCC) set the methodology and guidelines in 2006 (Čegir, 2021). The latter divides greenhouse gases per source: energy industries (1A1), manufacturing industries and construction (1A2), transport (1A3), other sectors (1A4 and 1A5) and fugitive emissions from fuels (1B) (IPCC, 2006). This dissertation focuses on the 1A and 1B categories. The main GHG in the energy sector is carbon dioxide, while methane appears in that category at the level of a few percentages. Most methane emissions fall within Category 1B, including venting, flaring, and fugitive emissions of fossil fuels. In the EU, two-thirds of 1B emissions were methane, and one-third were carbon dioxide (Čegir, 2021). Methane emissions from the 1B category arise along the entire supply chain of natural gas and crude oil (Čegir, 2021). Notably, methane fugitive emissions are subjected to high uncertainty since they are more difficult to track. For instance, some emitting events result from accidents and unpredictable process failures, which might contribute to large emissions from oil and gas operations. These are rarely included in the inventories (IEA, 2023).

The IPCC framework defines emission factors as "the emissions released into the atmosphere in the combustion process" (Lo Vullo et al., 2022). Furthermore, the IPCC Guideline is based on a three-tier methodology to quantify all GHG emissions, including methane, and it applies to all relevant emitting sectors (Čegir, 2021). Tier 1 is an elementary approach, providing simple estimations based on standard values for emission factors, and treating the whole system as one group or divided into only a few groups. Tier 2 is an intermediate approach, which measures values based on a specific country or region. Tier 3 provides instead the most precise estimations. It is country-specific and determined by experts from primary data (Čegir, 2021). However, for the goal of this dissertation, the Tier 1 approach will be used. The levels of monitoring and reporting vary between countries, sectors, and greenhouse gases (Čegir, 2021). Figure 3.1 illustrates the equation for calculating the direct emissions of each greenhouse gas from fossil fuel sources based on Tier 1 (IPCC, 2006).

$$Emissions_{GHG,\,fuel} = Fuel\ \ Consumption_{fuel} \bullet Emission\ \ Factor_{GHG,\,fuel}$$

Figure 3.1 Greenhouse Gas Emissions from Fossil Fuel Combustion (IPCC, 2006).

In detail, fuel consumption is given by the amount of fuel combusted expressed in terajoule (TJ). The default emission factor is calculated by multiplying a given GHG in kg with the TJ fuel type. The result is the amount of emissions of GHG when a certain fuel is burned (IPCC, 2006). Figure 3.2 shows the default emission factors for stationary combustion in the energy industry by using the abovementioned Tier 1 equation.

Fuel	CO_2		
	Default Emission Factor	Lower	Upper
Crude Oil	73 300	71 100	75 500
Natural Gas	56 100	54 300	58 300

Figure 3.2 Default Emission Factors for Stationary Combustion in the Energy Industry (IPCC, 2006).

From this first look, direct emissions of natural gas are lower compared to those of crude oil. From an emission point of view, using natural gas for power generation seems thus advantageous (IPCC, 2006). However, since the data reported in the figure refer only to the direct CO2 emissions, once the supply chains of natural gas and crude oil are considered, total emissions from the energy sector might significantly increase. Indeed, these contribute to more than three-quarters of total emissions (IEA, n.d.).

For the calculation of the Italian and Algerian direct and indirect emissions, the tonnes of CO2 equivalent are the unit of measurement selected for this dissertation.

3.2.2 CH4 Direct Emissions

The abovementioned equation can also apply to CH4 emissions (IPCC, 2006). The emission factors are converted from a certain number of tonnes of CH4 to tonnes of CO2eq using the 100-year Global Warming Potential (GWP). The latter describes the relative potency, molecule for a molecule of a greenhouse gas, considering how long it remains active in the atmosphere. Carbon dioxide is taken as the gas of reference with a 100-year GWP of 1. Methane has 28 times greater Global Warming Potential than carbon dioxide (Glossary: Global-warming potential, 2023). To convert the number of CH_4 emissions into CO_2 equivalent, it is necessary to multiply the former number by 28 times (Glossary: Global-warming potential, 2023). Indeed, it is important to calculate methane emissions because the energy sector accounted for 40 per cent of methane emissions from human activities and was responsible for nearly 135 million tonnes (Mt) of methane emissions in 2022 (IEA, n.d.).

3.3 Italian Direct Emissions in the Energy Sector

The first step to developing the demand function is to track the Italian downstream emissions. In Italy, most CO_2 emissions in the energy sector come from burning fossil fuels for power generation (IEA, 2021). Among them, natural gas is the major source of electricity and heating, accounting for 40.5 per cent. Whereas crude oil accounts for 35.3 per cent (IEA, 2021). However, when burned crude oil emits more CO_2 emissions and other pollutants than natural gas. The International Energy Agency reported that in 2022 Italian energy companies emitted 1.322.000.000 tCO_2 emissions from crude oil combustion, corresponding to 45 per cent of total emissions from fuel combustion and emitted 1.311.000.000 tCO_2 emissions from natural gas combustion, accounting for 44 per cent of total emissions from fuel combustion (IEA, 2021).

3.4 Carbon Pricing in the Energy Sector

In the current EU ETS, once it is verified how much CO_2 a specific input emits, a cap is set on the total amount of greenhouse gases that can be emitted by the installations and aircraft operators covered by the system (European Commission, n.d.). The cap "is expressed in emission allowances, where one allowance gives the right to emit one tonne of CO_2eq", corresponding to the carbon dioxide equivalent (European Commission, n.d.). Then, companies must surrender enough allowances to fully account for their emissions for each year in the system (European Commission, n.d.). The pricing of these allowances is determined by the supply and demand balance, which also establishes the marginal cost of emissions reductions necessary to meet the EU ETS cap (European Commission, n.d.). Indeed, a reasonable carbon price is an important condition to achieve this goal. Indeed, Dong et al. (2022) state that the efficiency of emissions reduction is usually negatively impacted if carbon prices stay low for an extended period because it erodes market participants' confidence. On the other hand, a higher carbon price level encourages the development of innovative green technologies and increases efficiency in reducing emissions. However, since Phase 1, the scheme has been affected by high carbon price volatility, with frequently low carbon prices. This price trend was mostly due to supply and demand factors, and geopolitical instability (Quercia, 2019). The war between Russia and Ukraine provides a recent example of how these latter factors influence the supply and demand of allowances in the energy sector. In 2021, prices increased as the global demand recovered after the pandemic, while supply remained tight due to subdued investments in the energy sector. Following Russia's invasion of Ukraine in early 2022, pipeline supply to Europe sharply reduced, resulting in record-high prices of oil and natural gas, and a drop in global demand (IEA, 2023). Indeed, Russia has a large footprint in the global natural gas and crude oil markets. Besides this country is deeply integrated into Europe's markets and distribution networks (Ari et al., 2022). This rise in fossil fuel prices is partially positive since it incentivises the use of renewables, and thus reduces emissions. However, simultaneously, a fossil fuel switch happens in favour of coal (Ari et al., 2022).

3.5 Indirect Emissions in the Energy Sector in the European Union

Indirect emissions on the path from oil and gas production to the final consumer, still lack a clear evaluation, thus raising several practical and methodological problems in tracking them (Laconde, 2018). Methane fugitive emissions are particularly challenging since they occur by accident or design along the supply chain (IEA, 2020). In the former case, it could be due to a faulty seal or leaking valve, while in the latter case, these emissions are carried out for safety reasons or due to the facility's or equipment's design. (IEA, 2020). Fugitive emissions occur mainly during fossil fuel extraction, transport, storage, and processing (Laconde, 2018).

The IPCC 2006 classifies the emissions from oil and natural gas systems in the subcategory 1.B.2 of the energy sector. A distinction is made between oil and natural gas' primary types of emission sources, namely venting, flaring and all other types of fugitive emissions. The latter category is further subdivided into the different parts of the crude oil or natural gas systems according to the type of activity (IPCC, 2006). These systems include all infrastructures required to produce, collect, process, refine, and deliver natural gas and petroleum products to market. The system begins at the wellhead, or oil and gas source, and ends at the final sales point to the consumer (IPCC, 2006). The number of fugitive emissions by the oil and gas sectors varies according to a country's circumstances and whether these two inputs are imported or exported (IPCC, 2006).

Since the European Union has a small natural gas and crude oil production, it emits low levels of methane emissions, and it appears to have a reduced methane footprint compared to other countries (Turitto, 2022). However, this made the EU one of the world's biggest natural gas and crude oil importers (Cooper et al., 2021). Therefore, a significant amount of methane emissions occurs along the supply chain of these two inputs in the exporting countries (Turitto, 2022). Thus, countries which are heavy importers are considered also large emitters and have a significant impact on emissions, such as Germany and Italy (Cooper et al., 2021). Still, Italy has higher emissions than Germany because it mainly imports from North Africa, especially Algeria, which has faced many issues related to fugitive emissions from pipelines. On the other hand, Germany mainly imports from Europe, which includes countries like Norway which has the lowest methane emissions (see Figure 3.3) (Cooper et al., 2021). That is to say that the number of fugitive emissions along the supply chain might also depend on the development and stability of the region of import (Laconde, 2018). Indeed, lower political stability, regulatory quality, and control of corruption might be associated with greater fugitive emissions, including flaring and venting, across countries and time (Calel and Mahdavi, 2020).

3.5.1 European Union Imports of Natural Gas and Crude Oil

Before diving into the different types of indirect emissions, and the supply chains of natural gas and crude oil, it is worth briefly describing the current situation of these two fossil fuels' imports in the European Union.

Until the end of 2021, Russia was the main supplier of crude oil and natural gas to the EU (Eurostat, 2023). After Russia invaded Ukraine in 2022, the European Union reacted with several sanctions, which directly and indirectly affected the trade of oil and natural gas. Consequently, new, and diversified suppliers emerged progressively (Eurostat, 2023). Concerning crude oil, Russia was the largest supplier to the EU in 2021 with a share of almost 25 per cent. As of 2023, its share dropped to 4 per cent, following the EU's ban on seaborne imports of Russian crude oil, and an embargo on refined oil products (Eurostat, 2023). Currently, the United States are the largest supplier of crude oil, followed by Norway, Libya, Iraq, and Kazakhstan (Eurostat, 2023).

Russia was the largest supplier of natural gas to the EU as well in 2021 with a share of 50 per cent. However, it now accounts for only 16 per cent, with Norway being the largest supplier, followed by Algeria (Eurostat, 2023).

3.5.2 Flaring and Venting

As mentioned, the IPCC classified indirect emissions into different categories. Overall, fugitive emissions can occur due to a faulty seal, leaking valve, or because of the specific design of equipment along the supply chain. Instead, flaring and venting occur when operators burn associated gas on a permanent or semi-permanent basis during production, or vent it to the atmosphere (IEA, 2023).

In detail, flaring can be divided into two main categories, such as routine flaring and non-routine flaring (Al Kamali, 2021). The former is an activity performed regularly during normal operations when it is uneconomical to recover the gas (Al Kamali, 2021). The non-routine flaring instead is an infrequent activity with high emission rates and short event duration. It happens because of conditions that occur outside the normal plant process and equipment operation as well as safety problems (Al Kamali, 2021). This latter reason is the practice of burning gas because it might contain hydrogen sulphide (i.e., sour gas). Thus, flaring would convert the highly toxic hydrogen sulphide gas into less toxic compounds (Earthworks, n.d.). However, at best, flaring emits a small pollutant into the air. At worst, a flare is defective and thus spews methane into the atmosphere (Sadek et al., 2022). For instance, between 15 and 25 per cent of natural gas produced in the United States is estimated to be "sour," or contaminated with hydrogen sulphide. Thus, this gas must go through a purification process to become marketable which leads to flare (Sadek et al., 2022). On the other hand, venting directly releases methane into the atmosphere. It occurs at several points in the oil and gas development process, including well completion, well maintenance, or pipeline maintenance (Earthworks, n.d.).

Most of the flaring occurs at oil wells, but some of it is also burned by companies that primarily produce and sell natural gas (Sadek et al., 2022). At oil wells, more than 140 billion cubic meters (bcm) of methane is burned off, that is flared, every year, transforming it into carbon dioxide. Just as much gas is released directly, vented, as methane, which makes as much as a 16-fold contribution to global warming (Calel and Mahdavi, 2020). Industry regulators and experts refer to these actions as a huge waste of resources, and money, besides being highly damaging to the atmosphere and the environment (Sadek et al., 2022). Indeed, flaring, and venting waste 8 per cent of global natural gas production annually, thus contributing to 6 per cent of global greenhouse gas emissions (Calel and Mahdavi, 2020). Companies claim that they flare and vent for safety and maintenance because selling or reusing that gas is not financially feasible. However, this statement is because companies flare and vent due to weak regulations, ineffective tracking, and a lack of economic incentives to capture and sell the gas (Sadek et al., 2022). This might be more frequent in developing countries due to financial barriers to implanting flare-reduction projects, low domestic gas prices, and lack of efficient government regulations (Buzcu-Guven and Harriss, 2012). Among the main natural gas and crude oil EU importers, are Russia, Algeria, Iran, and Iraq (Calel and Mahdavi, 2020). Despite being considered a developed country, the United States, another large oil and gas importer to the European Union, accounts for the largest methane emitter in natural gas and oil production, with 14.0 Mt of methane, as illustrated in Figure 3.3 (Sadek et al., 2022). The American Petroleum Institute stated that "flaring is necessitated by a lack of gas gathering lines or processing capacity and for safety reasons" (Sadek et al., 2022). Global methane emissions from oil and gas operations would decrease by more than 90 per cent if all producing nations were to match Norway's emissions intensity, which is the best-performing nation (IEA, 2023).

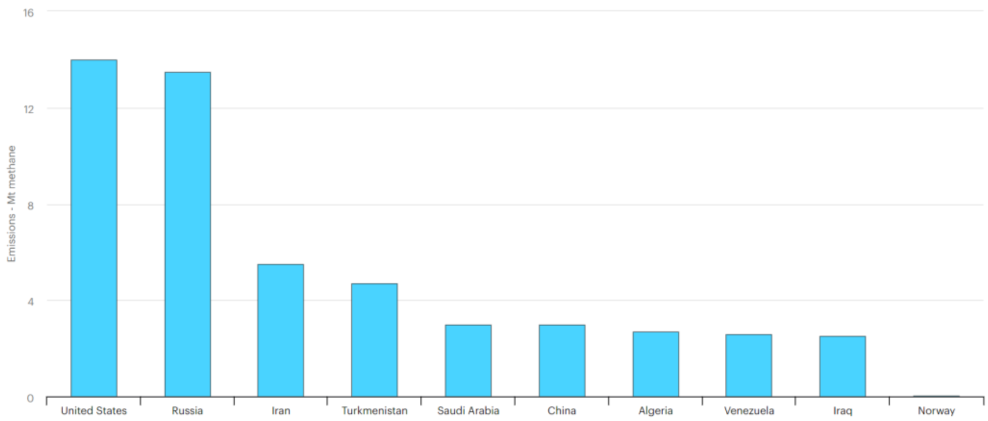

Figure 3.3 Oil and Gas Methane Emissions and Methane Intensity of Production in Selected Countries in 2022 (IEA, 2023).

Flaring and venting might be more challenging to track in the EU ETS. Flaring is highly visible both to the naked eye and to sensing instruments, thus it has a low-cost identification. On the contrary, vented gas is invisible and can only be detectable from a distance through the measurement of the atmospheric column's total methane concentration and comparison with background levels (Calel and Mahdavi, 2020). Even if these tools were available, the resolution would be too low and the uncertainty too high (Calel and Mahdavi, 2020).

3.6 Natural Gas Supply Chain

Compared to other fossil fuels, such as crude oil, natural gas has the lowest direct emissions from combustion, with 56 tCO_2/TJ (Lechtenböhmer and Dienst, 2010). Furthermore, its efficiency is around 58 per cent, much higher than other fossil fuels. Thus, both factors give natural gas a very positive picture in terms of GHG direct emissions. However, the high levels of GHG losses during the production, processing, transport, and distribution of natural gas, plus the increasing energy demand in Europe, could neutralise its low direct emissions advantage (Lechtenböhmer and Dienst, 2010). This is particularly evident when also considering the long distances of natural gas transmission to Europe and the still strong dependence on this input from high-emitting countries. All these factors contribute to increasing GHG emissions in the upstream and midstream segments in the gas supply chain (Lechtenböhmer and Dienst, 2010). Most importantly, the main source of GHG losses is fugitive and vented methane, which is an extremely potent GHG over short time scales compared to CO_2 (Balcombe et al., 2016).

In detail, the entire supply chain of natural gas represents an integrated process, comprising the upstream, midstream, and downstream segments. The upstream sector is responsible for exploring and producing natural gas, including bringing this resource to the surface (Mette, 2021). The midstream segment refers to processing natural gas and anything required to transport and store it. This sector includes pipelines, and all the infrastructures needed to transport it (Mette, 2021). Finally, the downstream sector is responsible for its selling and distribution to the final consumer, namely, power generation, industries, and private households (Mette, 2021). The next subsections present the upstream and the midstream segments in more detail and their related CO_2, especially CH_4 emissions. The downstream segment is not presented since it is already included in the current EU ETS.

3.6.1 Upstream Segment

Emissions in the upstream segment are usually associated with site preparation, drilling, hydraulic fracturing, and extraction, especially from equipment fuel usage (Balcombe et al., 2018). This segment starts with a pre-production stage which includes reservoir exploration, site preparation, drilling, and well completion. Exploration covers geophysical prospecting, such as seismic assessment, and exploratory drilling. In this initial phase, some emissions of both methane and CO_2 are likely but make only a small contribution (Balcombe et al., 2018; Balcombe et al., 2016). Site preparation and drilling emit mostly CO_2 emissions, especially from fuel requirements (Balcombe et al., 2016). However, these phases only make up minor part of the emissions from the entire supply chain (Balcombe et al., 2016). Furthermore, well completion includes a series of procedures including cementing and casing the drilled well, performing hydraulic fracturing on the well if necessary, and returning the fracturing fluid to the well before starting gas extraction (Balcombe et al., 2016). Hydraulic fracturing is an energy-intensive process resulting in CO_2 emissions from fuel usage. Indeed, these latter activities are the main sources of emissions in this first segment of the natural gas supply chain (Balcombe et al., 2018). Notably, emissions from well completion can be highly variable since they mostly depend on the well type, the completion equipment, and whether any emissions are vented or flared (Balcombe et al., 2018).

Once the well is complemented, the extraction and production of natural gas begin (Balcombe et al., 2016). Emissions from production are usually leaks and vents, workover emissions, and liquid unloading. If workover and liquid unloading are not included, methane leaks and vents arise from pneumatic device vents, compressors, condensate storage tank vents, and fugitive emissions. These are estimated to be below 1 per cent of produced methane (Balcombe et al., 2016). In detail, workovers include several operations, such as repairing leaks and re-perforating or cleaning the well bore (Balcombe et al., 2016). The number of workovers required per well varies, from zero to five workovers per well lifetime (Balcombe et al., 2016). Furthermore, liquid unloading is another key emissions source, consisting of removing the liquids accumulated at the bottom of the well to improve gas flow (Balcombe et al., 2016). However, the quantity of emissions of this activity depends upon several factors, such as the well characteristics, the well age, the different equipment to perform unloading, and the operation procedure (Balcombe et al., 2016).

3.6.2 Midstream Segment

Processing natural gas is the first stage of the midstream segment, and the main sources of emissions are the fugitive and vented CH_4 and CO_2 emissions from pieces of equipment such as compressors and reboilers (Balcombe et al., 2016). Contrary to the extraction sites, processing facilities tend to be permanently manned, and thus leakages are lower (Balcombe et al., 2016). Among these methane emissions, the main sources are liquid storage tank vents, namely flashing liquids, pneumatic valve venting, and compressor and pipework leaks. Venting of CO2 during the CO2 removal phase is another large source of GHG emissions during the processing of natural gas (Balcombe et al., 2016). This phase can contribute to up to 50 per cent of the processing GHG emissions. Furthermore, a small amount of gas is flared, usually less than 0.5 per cent of produced natural gas (Balcombe et al., 2016).

Natural gas transmission is the second stage of the midstream segment, and emissions arise from combustion emissions from gas-fuelled compressors and methane leaks and vents from pipelines, compressors, and gas-driven pneumatic devices (Balcombe et al., 2016). Although the distances might be highly variable across different networks, transmission pipelines usually require compressor stations every 80−160 km, and average transport distances about approximately 1000 km (Balcombe et al., 2016).

The transmission stage accounts for the main source of GHG emissions from the natural gas chain (Lechtenböhmer and Dienst, 2010). They can originate from the transport distances, related to the CO2 emissions from fuel gas consumption for transport, and the transport infrastructure, related instead to CH4 emissions (Lechtenböhmer and Dienst, 2010). Indeed, the emissions here are highly dependent on the quality of the transport system, including valves, compressor stations, and pipelines, its maintenance, and the overall management of the gas transport (Lechtenböhmer and Dienst, 2010).

3.6.3 Algerian Natural Gas to Italy

In reaction to the EU sanctions imposed on Russia after the conflict between Russia and Ukraine, Algeria became the single biggest gas supplier to Italy in 2022, remaining strong so far in 2024 (Butt, 2023). Pipeline gas supply from Algeria to Italy has a main entry point, the TransMed pipeline, which sees gas flow to the mainland, particularly in Sicily in Mazara del Vallo via Tunisia (Butt, 2023). TransMed has an annual capacity of 33 billion cubic metres (bcm) and started commercial operation in 1983 (Ouki, 2023). However, the main issue is that Algeria accounts for high methane emissions in both the upstream and midstream segments of the supply chain due to poor quality of equipment and maintenance (IEA, 2023). Indeed, it has timeworn pipelines and equipment, especially for gas lines installed between 1961 and 2001, leading to high levels of methane fugitive emissions (Louhibi–Bouiri and Hachemi, 2018).

3.7 Crude Oil Supply Chain

Currently, the combustion of petroleum fuel accounts for about 34 per cent of annual greenhouse gas (GHG) emissions worldwide; the extraction, transportation, and refining of crude oil contribute an additional 9 per cent of GHG emissions (Dixit, 2021). This significant percentage of emissions is distributed across a complex global trade network which transports hundreds of crude blends over pipelines and ocean shipping thousands of miles long via interconnected trade networks and then refined at the refineries (Dixit et al., 2023). As for natural gas, the crude oil supply chain comprises three stages. The upstream is the first one and includes the extraction of crude from oil fields. This is followed by the midstream segment which is responsible for the transportation of crude oil via pipelines, rail, trucks, and tankers, and its refining (Dixit, 2021). The downstream segment is responsible for the distribution, but it is already included in the EU ETS.

3.7.1 Upstream Segment

The upstream segment is responsible for the extraction of crude oil. This process requires drilling the well to extract hydrocarbons from the reservoirs, and then processing them (Dixit, 2021). In some cases, it is necessary to use enhanced recovery techniques that pump water or gases into underground cracks (Dixit, 2021). These extraction operations are energy-intensive and represent the first key source of GHG in the crude oil supply chain (Dixit, 2021). When crude oil is extracted, gas dissolved in it is released. This might be used for meeting energy needs in extraction, captured and sold as a product, or flared and vented (ICCT, 2010). Furthermore, this process might release fugitive emissions as well, from valves and mechanical seals (ICCT, 2010). To create "crude blends" that are marketed and supplied to refineries, the extracted crude is stabilized and mixed (Dixit, 2021). This process is significant in the supply chain as it identifies the signature for oil barrels (Dixit, 2021).

3.7.2 Midstream Segment

The midstream segment starts with the transportation of crude blends to their destinations, such as the refineries, via pipelines, rail, trucks, and tankers depending on the producers and consumer countries (Dixit, 2021). The GHG emissions during this stage vary according to the distance and the mode of transport (ICCT, 2010). Once the crude blends reach the destination, they are refined to form petroleum products such as gasoline, or jet fuel (Dixit, 2021). This stage uses various chemical separation and reaction processes to transform crude oil into usable products, the amount of CO_2 and CH_4 mostly depends on the sulphur content of the crude blends and the type of refinery (ICCT, 2010).

3.7.3 Algerian Crude Oil to Italy

Algeria accounts for the upstream and midstream segments since it extracts and transports crude oil. However, the refinery stage is slightly more complicated to verify since crude blends can be refined both in Algeria and by Algerian energy companies in Italian refineries. For instance, in 2018 one of the biggest state-owned energy companies in Algeria, Sonatrach, bought the Italian refinery in Augusta, Sicily. This same year, Sonatrach also bought refineries in Palermo and Naples previously owned by Esso Italia (Indelicato, 2018). This investment occurred because Algeria has been struggling to meet the demand for crude oil and has been facing high costs for refining it. Thus, the company decided to divert these costs and move this stage to Italy (Indelicato, 2018). However, the Augusta refinery is old since it was installed in 1951, and even at that time, it was considered obsolete. Now this refinery is still working, thus emitting high amounts of GHG (D'Orsogna, 2018).

This dissertation will, however, count the refinery's midstream emissions emitted in Algeria.

3.8 Calculation of Upstream and Midstream Emissions of Natural Gas and Crude Oil in Algeria

This section presents the number of methane indirect emissions in the upstream and midstream segments from the Algerian natural gas and crude oil supply chains. These data will then add to the direct emissions from fossil fuel combustion in the downstream segment of Italy.

Algeria's National Inventory Report of 2023, submitted under the UNFCCC, calculated CO_2 and CH_4 indirect emissions during the upstream and midstream natural gas and crude oil supply chains in 2020, according to the IPCC 2006 guidelines (Ministry of the Environment and Renewable Energy, 2023). This dissertation focuses only on methane fugitive emissions, which in the National Inventory are reported in kilotons (kt) of CH_4. These numbers will be converted into tonnes of CH_4, and then their CO_2 equivalent will be calculated by multiplying the result by 28, corresponding to the Global Warming Potential (GWP) of methane.

The sources of fugitive emissions on oil and gas systems are mainly from equipment leaks, evaporation, flashing losses, and venting and flaring. Most CH4 emissions come especially from the production, transformation, and transport of natural gas since Algeria is a gas country (Ministry of the Environment and Renewable Energy, 2023). For estimating these emissions from oil and natural gas systems, the Tier 1 method was applied, as illustrated in the equation in Figure 3.4. This also includes vented and flaring emissions (Ministry of the Environment and Renewable Energy, 2023).

$$\frac{Emissions_{gas,\ industry\ segment} =}{AD_{industry\ segment} * EF_{gas,\ industry\ segment}}$$

Figure 3.4 Fugitive Emissions from an Industry Segment with the Tier 1 Approach (Ministry of the Environment and Renewable Energy, 2023).

The emissions of methane are thus calculated by multiplying the activity data of different industry segments with the default emission factor for different industry segments (Ministry of the Environment and Renewable Energy, 2023).

3.8.1 Algerian Upstream Emissions of Natural Gas

In Algeria's National Inventory Report of 2023, only the production process was accounted for in the upstream segment. This includes fugitive emissions from onshore production, such as equipment leaks, venting, and flaring, from the gas wellhead through the inlet of gas processing plants, or, to the tie-in points on gas transmission systems (Ministry of the Environment and Renewable Energy, 2023). In this stage, wells are used to withdraw raw gas from underground formations (Ministry of the Environment and Renewable Energy, 2023). Methane represents the most important gas in the production process, accounting for 99.50 per cent of 2020 emissions, resulting mainly from leakages (Ministry of the Environment and Renewable Energy, 2023). To estimate CH4 fugitive, vented, and flared emissions in natural gas production, the Tier 1 method was applied using the equation in Figure 3.5.

$$\begin{aligned} Emissions_{Natural\ gas\ production} &= AD_{Natural\ gas\ production} * EF_{leaks} \\ &+ AD_{Natural\ gas\ production} * EF_{venting} \\ &+ AD_{Natural\ gas\ production} * EF_{flaring} \end{aligned}$$

Figure 3.5 Fugitive Emissions from the Natural Gas Production Process with the Tier 1 Approach (Ministry of the Environment and Renewable Energy, 2023).

The number of emissions in the natural gas production process is calculated by multiplying the activity data on the production of conventional natural gas with the default emission factor of CH4 for fugitive emissions from leaks, venting, and flaring from this activity (Ministry of the Environment and Renewable Energy, 2023). According to Algeria's National Inventory Report of 2023, the total methane fugitive emissions from natural gas production amounted to 302.37 kt in 2020 (Ministry of the Environment and Renewable Energy, 2023). The conversion from kt in tons of this value corresponds to 30.237.000 tons of methane.

3.8.2 Algerian Midstream Emissions of Natural Gas

The natural gas midstream segment includes its processing and transport. Concerning the former, the fugitive emissions come from the processing facilities, including equipment leaks, venting, and flaring, compressors, pneumatic controllers, and uncombusted gas from engines (Ministry of the Environment and Renewable Energy, 2023). During this stage, methane emissions account for 13 per cent of venting and flaring (Ministry of the Environment and Renewable Energy, 2023). For estimating fugitive emissions of CH4 the Tier 1 method according to the 2006 IPCC was used, as shown in the equation in Figure 3.6.

$$\boldsymbol{Emissions_{Natural\ gas\ processing} = AD_{Natural\ gas\ processing} * EF_{All}}$$

Figure 3.6 Fugitive Emissions from the Natural Gas Processing Process with the Tier 1 Approach (Ministry of the Environment and Renewable Energy, 2023).

The number of emissions of the natural gas processing is calculated by multiplying the activity data on the volume of natural gas processed with the default emission factor of CH4 for fugitive emissions from "All", that is the sum of leaks, venting, and flaring (Ministry of the Environment and Renewable Energy, 2023). This equation results in 94.15 kt of methane, which corresponds to 9.415.000 tons of methane (Ministry of the Environment and Renewable Energy, 2023).

The fugitive emissions from the last stage of the natural gas midstream segment, transmission, come from systems used to transport processed natural gas to market. This activity also includes its storage systems. Gas is transported over long distances by high-pressure, large-diameter pipelines from field production and processing areas to distribution systems or large-volume customers like chemical or power plants (Ministry of the Environment and Renewable Energy, 2023). As mentioned, Algeria has timeworn pipelines and poor maintenance, thus the fugitive emissions at this stage are high, composed of mostly methane leaks during the transmission of natural gas, corresponding to 99.07 per cent of the 2020 emissions (Ministry of the Environment and Renewable Energy, 2023). The Tier 1 method was applied to estimate them, as illustrated in Figure 3.7.

$$\boldsymbol{Emissions_{Transmission\ and\ storage} = AD\_Natural\_gas_{Transmission} * EF_{All\_transmission\_Natural\_gas} + AD\_Natural\_gas_{Storage} * EF_{All\_strorage\_Natural\_gas}}$$

Figure 3.7 Fugitive Emissions from Natural Gas Transmission with the Tier 1 Approach (Ministry of the Environment and Renewable Energy, 2023).

The number of fugitive emissions is calculated by multiplying the activity data by the length of the transmission pipeline with the default emission factor of CH4 for fugitive emissions from “All”, which includes the sum of leaks, venting, and flaring of natural gas transmitted (Ministry of the Environment and Renewable Energy, 2023). The same equation is applied to the fugitive emissions in the storage activity. Thus, the fugitive emissions from the transmission and storage stages amounted to 288.15 kt in 2020 (Ministry of the Environment and Renewable Energy, 2023). This latter value converted in tons of methane corresponds to 28.815.000 tons.

Furthermore, the sum of the upstream and midstream segments’ fugitive methane emissions amounts to 735 kt, which converted into tons of methane are 735000 tons (Ministry of the Environment and Renewable Energy, 2023).

3.8.3 Total Natural Gas Upstream and Midstream Fugitive Emissions

Overall, Algeria emitted 69.202.000t of methane fugitive emissions in 2020 along the upstream and midstream segments (Ministry of the Environment and Renewable Energy, 2023). As above mentioned, for this thesis, it is necessary to calculate the tons of methane in their CO2 equivalent by multiplying this latter value by 28. The result is 1.937.656.000tCO2eq from the Algerian supply chain. The upstream segment and the transmission process in the midstream segment represent the most methane-emitting stages of the natural gas supply chain (Ministry of the Environment and Renewable Energy, 2023). These are concerning results since methane is a powerful greenhouse gas, and thus an important factor in global warming (Louhibi–Bouiri and Hachemi, 2018). Indeed, methane's lifetime, once released into the atmosphere, is around 12 years, but it is 28 times more potent at trapping atmospheric heat than CO2 over a 100-year timescale (Louhibi–Bouiri and Hachemi, 2018). This is to say that, despite natural gas's downstream emissions being lower than other fossil fuels, its upstream and midstream emissions are significant, especially because they are mostly methane emissions. Thus, tracking and including the natural gas value chain and CH4-related emissions can become pivotal in the EU ETS to meet its mitigation and GHG emissions reduction goal.

3.8.4 Algerian Upstream Emissions of Crude Oil

According to Algeria's National Inventory Report of 2023, the extraction and production of crude oil in the upstream segment include fugitive emissions from equipment leaks, venting and flaring, on-site crude oil processing, wellhead leaks, well-site equipment, untreated transport, condensate removal, and upgrading facilities (Ministry of the Environment and Renewable Energy, 2023). During this stage, methane emissions are about 18.7 per cent, mainly resulting from losses in oil production and upgrading (Ministry of the Environment and Renewable Energy, 2023). As for natural gas, fugitive, venting, and flaring emissions of CH4 from oil extraction and production are estimated using the Tier 1 method, as illustrated in the equation in Figure 3.8.

$$\begin{aligned} \boldsymbol{Emissions_{oil\,production}} &= \boldsymbol{AD_{oil\,production}} * \boldsymbol{EF_{leaks}} \\ &+ \boldsymbol{AD_{oil\,production}} * \boldsymbol{EF_{venting}} \\ &+ \boldsymbol{AD_{oil\,production}} * \boldsymbol{EF_{flaring}} \end{aligned}$$

Figure 3.8 Fugitive Emissions from Crude Oil Extraction and Production with the Tier 1 Approach (Ministry of the Environment and Renewable Energy, 2023).

The number of total CH4 emissions from this stage is calculated by multiplying the activity data on the extraction and production of crude oil with the default emission factor of CH4 for fugitive emissions from leaks, venting, and flaring from this activity (Ministry of the Environment and Renewable Energy, 2023). The total emissions thus amounted to 58.75 kt in 2020 (Ministry of the Environment and Renewable Energy, 2023). This value converted into tons of methane corresponds to 5.875.000t.

3.8.5 Algerian Midstream Emissions of Crude Oil

Transportation of crude oil is the first stage of the midstream segment. It includes fugitive, flaring, and venting emissions related to the transport of marketable crude oil to upgraders and refineries. Evaporation losses from storage, filling and unloading activities and fugitive equipment leaks are the primary sources of these emissions (Ministry of the

Environment and Renewable Energy, 2023). Notably, Algeria's transportation systems are comprised mainly of pipelines. The petroleum products are transferred to marine tankers to be transported to Italy (Ministry of the Environment and Renewable Energy, 2023). Occasionally, tank trucks and rail cars are used for short transport (Ministry of the Environment and Renewable Energy, 2023). The key gas in oil transport is methane, accounting for 99.3 per cent of 2020 emissions, and mainly resulting from leakage and evaporation from oil transport and storage (Ministry of the Environment and Renewable Energy, 2023). To estimate fugitive, venting, and flaring emissions of CH4 from this stage, the Tier 1 approach was applied, as shown in Figure 3.9.

$$\boldsymbol{Emissions_{oil\ transport} = AD_{pipelines} * EF_{pipelines}}$$

Figure 3.9 Fugitive Emissions from Crude Oil Transport with the Tier 1 Approach (Ministry of the Environment and Renewable Energy, 2023).

The number of fugitive emissions from crude oil transport is provided by multiplying the volume of oil transported by pipelines with the default emission factor of CH4 for oil transported by pipelines (Ministry of the Environment and Renewable Energy, 2023). The result amounted to 0,65 kt in 2020, which in tons is equivalent to 650t of methane. This outcome shows that oil transport emits fewer methane fugitive emissions than other operations, which might be due to the control of leakages in this activity during the last few years (Ministry of the Environment and Renewable Energy, 2023).

The refinery is the second stage of crude oil midstream operations, which includes fugitive emissions from equipment leaks, venting, and flaring (Ministry of the Environment and Renewable Energy, 2023). During this stage, methane fugitive emissions come from storage tanks, blowdowns, asphalt blowing, equipment leaks, vents, and loading operations (Ministry of the Environment and Renewable Energy, 2023). To estimate the number of these emissions, the Tier 1 method was applied, as in Figure 3.10.

$$\begin{aligned}\boldsymbol{Emissions_{refining}} &= \boldsymbol{AD_{oil\ refining} * EF_{oil\ refining-leaks}} \\ &+ \boldsymbol{AD_{oil\ refining} * EF_{oil\ refining-venting}} \\ &+ \boldsymbol{AD_{oil\ refining} * EF_{oil\ refining-flaring}}\end{aligned}$$

Figure 3.10 Fugitive Emissions from Crude Oil Refineries with the Tier 1 Approach (Ministry of the Environment and Renewable Energy, 2023).

The total number of fugitives, venting, and flaring CH4 emissions are calculated by multiplying the activity data of oil refining with the default emission factor of CH4 for leaks, venting, and flaring for this activity (Ministry of the Environment and Renewable Energy, 2023). This equation provided the result of 284 kt in 2020 (Ministry of the Environment and Renewable Energy, 2023). This number converted into tons corresponds to 284.000t.

3.8.6 Total Crude Oil Upstream and Midstream Fugitive Emissions

Overall, Algeria emitted 6.159.650t of methane emissions in 2020 along the supply value chain of crude oil (Ministry of the Environment and Renewable Energy, 2023). As for natural gas, this value converted into CO2 equivalent emissions is equivalent to a total of 172.470.200tCO2eq. In the crude oil supply chain, the upstream segment accounts for the high-emitting stage, followed by the refinery process and transportation in the midstream segment (Ministry of the Environment and Renewable Energy, 2023).

3.8.7 Discussion

The next stage of this dissertation is, to sum up the upstream, midstream, and downstream segments of natural gas and crude oil to verify the total CH4 emissions from their extraction starting in Algeria to their combustion in Italy. The total methane fugitive, venting, and, flaring emissions of natural gas are 3.248.656.000tCO2eq, while those of crude oil are 1.494.470.200tCO2eq (Ministry of the Environment and Renewable Energy, 2023).

In light of these data, it can be observed that both natural gas and crude oil supply chains have significant levels of methane emissions along their supply chains. Contrary to the downstream emissions, once all the natural gas supply chain segments are added, this input does not have the same climate advantage over crude oil. Indeed, considering these results, the natural gas supply chain emits a greater amount of methane emissions than the crude oil supply chain from leakages, venting, and flaring (Ministry of the Environment and Renewable Energy, 2023). Most importantly, methane is released when natural gas leaks (Gordon and Hughes, 2023). The International Energy Agency confirms these outcomes in reporting that indirect emissions from crude oil account for between 10 per cent and 30 per cent of its supply chain emissions intensity, while those from natural gas account for between 15 per cent and 40 per cent (IEA, 2020).

A possible issue at the centre of these results, and related to the EU ETS as well, is that while carbon dioxide has dominated climate change and emissions reduction conversations for years, methane has not been considered yet. Indeed, cutting methane emissions is a low-hanging fruit since it would deliver bigger GHG reductions sooner (Gordon and Hughes, 2023). For this dissertation, the upstream and midstream segments and methane, as further gas, should be tracked and included in the European Union Emissions Trading System. In doing so, upstream, and midstream segments would be tracked in the same way as the downstream segment in the system, in which methane emissions are priced as CO2. These changes would encourage EU ETS companies to increase their efforts in reducing GHG emissions and accelerate the path towards mitigation and decarbonisation in the energy industry.

3.9 The Demand Function

3.9.1 The Theory

This section develops a demand function which aims at analysing the EU ETS firm's choice after the upstream and midstream methane emissions of natural gas and crude oil are calculated in the system. As noted above, the EU ETS currently calculates and prices only the downstream CO2 emissions of these two inputs, and the most environmentally and economically advantageous fossil fuel is natural gas (IPCC, 2006). Besides being the most used fossil fuel in the power sector in Italy (IEA, 2021). However, after the supply chain and methane emissions of natural gas have been tracked, this fossil fuel does not seem so advantageous anymore, since the supply chain CH4 emissions of natural gas imported from Algeria to Italy amounted to 3.248.656.000 tCO2eq., while those of crude oil to 1.494.470.200 tCO2eq (Ministry of the Environment and Renewable Energy, 2023). Indeed, developing the demand function will guide the Italian firm towards the optimal fossil fuel choice from Algeria, corresponding to the least environmentally impactful in terms of methane emissions and the most economically feasible when buying EUA permits.

From a theoretical point of view, the demand function refers to the relationship between the price of a good or service in a particular market and the quantity demanded for a specified time frame (Kenton, 2024). The demand function is represented by an equation and a graphic, namely the demand curve (Kenton, 2024). The former "is defined by $p=f(x)$, where p measures the unit price and x measures the number of units of the commodity in question" (Economic models, n.d.). The decreasing function of x generally characterises the demand function equation, as p increases. The demand curve reflects this equation and is typically displayed with the price on the left vertical or y-axis and the quantity demanded on the horizontal or x-axis. The demand curve generally tends to slope down from left to right, because when the price rises, the demand usually drops (Kenton, 2024). Indeed, this illustrates the price elasticity of demand, which quantifies how a product's consumption changes in response to price changes (Kenton, 2024). However, the equation and the demand curve can vary according to the product or service type (Kenton, 2024). Furthermore, the change in the price-demand relationship might lead to product substitution, as occurred in the EU ETS when natural gas and crude oil prices increased bringing firms back to coal (Kenton, 2024; Grubb and Neuhoff, 2006).

Furthermore, the demand function can be distinguished into linear and nonlinear (Nasrudin, 2022). A linear demand function means that a linear relationship between the quantity demanded of a product or service and its price is drawn. Indeed, it is a straightforward form of the demand function since the changes in the price of a good or service proportionally result in changes in the quantity demanded, with no other influencing factors (*Demand Function*, n.d.). Mathematically, it can be represented as

$$Qd = a - bP$$

Qd is the quantity demanded, a is the constant indicating the quantity demanded when the price is zero, and it is often referred to as intercept. P is the price of the good or service, and b is the slope which shows how much the quantity demanded changes as the price changes (*Demand Function*, n.d.). On the other hand, a demand function is nonlinear when the quantity demanded is a non-linear function of the price, and thus this relationship forms other than a straight line (*Demand Function*, n.d.). This thesis uses a linear demand function.

3.9.2 The Demand Function in the EU ETS

The demand function of this dissertation is based on the above-noted theory and the price rules to calculate CO2 emission allowances, where one allowance gives the right to the participating firms to emit one tonne of CO2eq (European Commission, n.d.). Thus, once the Italian firm of this dissertation enters the EU ETS, it has a cap on emissions allowed to emit. Still, this time the one allowance corresponds to one tonne of methane fugitive emissions expressed in CO2eq, from the Algerian supply chain of natural gas and crude oil. To verify how the choice of the Italian firm will change after the inclusion of the methane supply chain emissions in the EU ETS, the demand equation for crude oil is developed as follows:

*Oil = A_oil - B_oil *(P_oil + p* X_oil)*

Whereas the demand equation of natural gas is developed as follows:

*Gas = A_gas - B_gas *(P_gas + p* X_gas)*

A_oil and *A_gas* represent the constant indicating the quantity demanded when the price is zero, often called the intercept (*Demand Function*, n.d.). *B_oil* and *B_gas* indicate the demand elasticity of natural gas or crude oil, which measures how the demand changes when the price increases or decreases. This parameter helps understand how consumers adjust their consumption habits when the price of a product changes (*Demand Function*, n.d.). Furthermore, *P_oil and P_gas* represent the price of crude oil and natural gas respectively. Natural gas's price is 2,21USD/MMBtu and crude oil price is 78,82 USD/Bbl (TRADING ECONOMICS, n.d.). Whereas *p* is the current price of carbon permits, corresponding to 73,3EUR. It decreased by 12.22 EUR or 14.75 per cent since the beginning of 2024 (TRADING ECONOMICS, n.d.). This price trend is due to reduced industrial activity, meaning lower emissions and a need to surrender fewer allowances, and a change in the power mix, characterised by a stronger use of renewables across Europe and due to the energy crisis in the aftermath of the Russia-Ukraine War which caused some switching from gas to coal-based generation (Patterson, 2023; Supply and Demand in the EU ETS, 2023). Finally, *X_oil and X_gas* correspond to the number of emission permits set in the cap by the European Union (European Commission, n.d.). In this thesis, these two parameters equal the number of the Italian firm's downstream emissions, such as 1311.000.000tCO2 for *X_gas* and 1322.000.000tCO2 for *X_oil* (IEA, 2021).

However, to calculate how the demand for natural gas and crude oil from Algeria would change after the inclusion of the methane supply chain emissions, two new parameters are included, namely *X'_gas* and *X'_oil*. These equal the total methane emissions of the natural gas and crude oil from the Algerian upstream and midstream segments to the Italian downstream segment. The value of *X'_gas* is 3.248.656.000tCO2eq, and the value of *X'_oil* is 1.494.470.200tCO2eq (Ministry of the Environment and Renewable Energy, 2023). Thus, the equation to calculate how the demand will change after the inclusion of these two new values, is developed as follows:

$$Change\_oil = -\ B\_oil\ (X'\_oil - X\_oil)$$

$$Change\_gas = -\ B\_gas\ (X'\_gas - X\_gas)$$

Change_oil and *Change_gas* represent the variation of the demand. Whereas -*B_gas* and -*B_oil* correspond to the elasticity of the demand for these two inputs. In this case, the firms' production, and consumption of these two inputs might vary after the change in demand and policy structure. Therefore, $Change\_oil = -\ Change\_gas$ is imposed. This equation is thus developed as follows:

$$(X'\_oil - X\_oil) = -\ B\_gas\ (X'\_gas - X\_gas) / B\_oil$$

$$Change\_oil = B\_gas\ (X'\_gas - X\_gas)$$

$$Change\_gas = -\ B\_gas\ (X'\_gas - X\_gas)$$

Once the values are replaced with the parameters, the equation is:

$$Change\_oil = B\_gas\ (3.248.656.000tCO2eq - 1311000000tCO2)$$

$$Change\_gas = -B\_gas\ (3.248.656.000tCO2eq - 1311000000tCO2)$$

Thus, the demand for natural gas and crude oil after the inclusion of the supply chain methane emissions in the EU ETS changes by about 1.937.656.000tCO2eq.

Furthermore, a different equation to calculate how the demand might change is if one supposes that the number of permits to produce natural gas increases, with the equation being $X'\_gas - X\_gas = 10\ EUR/tep$, with a symmetrical reduction of the number of permits to use crude oil corresponding to 10 EUR/ton. In this case, the firms' production and consumption of natural gas and crude oil do not change with the demand and policy structure. Thus, this thesis attempts to calculate the impact on methane emissions and demand. The equation is the following:

$$Change\_oil = B\_gas * 10$$

$$Change\_gas = -\ B\_gas * 10$$

$$Change\_emissions = Change\_oil * CI\_oil + Change\_gas * CI\_gas$$

CI_oil and *CI_gas* correspond to the carbon intensity of crude oil and natural gas respectively. The carbon intensity is the emission rate of a certain pollutant (i.e. carbon dioxide) relative to the intensity of an activity or industrial production process (*Emission intensity,* 2024). This value is obtained by dividing the total methane supply chain emissions of the two inputs by the respective total production of natural gas and crude oil in Algeria in 2020, namely 79.944 toe (tons of oil equivalent) of natural gas and 42.567 tons of crude oil (Ministére de l'Énergie et des Mines, 2021). Thus, the *CI_oil* corresponds to 35.108,65 tCO2eq/tons and the *CI_gas* is 40.636,64tCO2eq/toe. The values of the above equation are the following:

*Change_emissions = B_gas * 10* 35.108,65 tCO2eq/ton - B_gas * 10 * 40.636,64 tCO2eq/tep*

*Change_emissions = - B_gas * 10 * (40.636,64tCO2eq/tep - 35.108,65tCO2eq/ton)*

*Change_emissions = - B_gas * 10 * 5.527,99tCO2eq/ton*

Change_emissions = -55.279,9tCO2/ton

-55.279,9tCO2eq/ton represents the impact on methane emissions of natural gas and crude oil after the increase in the number of permits to produce natural gas and the decrease in permits for crude oil. First, this result proves that it is possible to obtain a Pareto efficiency allocation of emissions when an increase in the number of permits in the EU ETS occurs. According to the economic theory, a Pareto efficiency is "an economic state where resources cannot be reallocated to make one individual better off without making at least one individual worse off" (Rasure and Logan, 2024). That is to say that the increase in the number of permits does not represent a positive factor in the EU ETS since it allows firms to emit more greenhouse gas emissions without additional costs (Abrell et al., 2011). Nonetheless, the equation reports a decrease in methane emissions, which indicates that the cap-and-trade scheme is reaching its emissions reduction goals.

However, this same result also demonstrates that the EU ETS might have been promoting the wrong input for the power sector, namely natural gas. Indeed, the increase in the number of permits for natural gas, allowed firms within the EU ETS to produce higher quantities of CO2 and methane, without additional costs (Abrell et al., 2011). On the contrary, a reduction in permits for crude oil constrains power plants to emit less GHG, without additional costs (Abrell et al., 2011).

This situation is hypothesised, however, as the outcomes in Section 3.8 demonstrate, natural gas does not represent the most environmentally and economically advantageous input compared to crude oil in the energy sector in the EU ETS. Notably, in the case of the above-mentioned Italian power plant which imports natural gas and crude oil from Algeria. Indeed, this specific example worsens the situation even more, since Algeria is one of the number one exporters of natural gas to Italy, especially in the aftermath of the Ukraine-Russia war (Eurostat, 2023). Algerian's timeworn pipelines and poor maintenance contributed to the increase in the number of fugitive methane emissions along the supply chain of natural gas (Louhibi–Bouiri and Hachemi, 2018). On the other hand, crude oil does not represent the cleanest fossil fuel in the market and the most environmentally and economically optimal choice, however, compared to natural gas's large methane-emitting supply chain, it could represent a better choice for the Italian firm within the EU ETS. It has fewer methane fugitive emissions along the upstream and midstream segments, and Algeria has been controlling more fugitive emissions during the transport of crude oil (IPCC, 2006; Ministry of the Environment and Renewable Energy, 2023).

That is to say that it might be clear that the European Union Emissions Trading System has not been efficient in meeting its emission reduction goals since it has been promoting the least environmentally advantageous input mix, and it has not yet included the most powerful greenhouse gas, methane, especially in its major source, the supply chain of fossil fuels.

3.10 Suggestions and Discussions

This section attempts to provide some suggestions to make the EU ETS more efficient in reducing the greenhouse gas emissions of the participating countries, and thus meet its goals and keep up with the increasingly stringent European climate policies (*Climate Change: What the EU Is Doing*, n.d.).

Simultaneously with the introduction of the maritime sector in the EU ETS in 2024, other greenhouse gas emissions, besides CO2, will be counted in the system from 2026, including nitrogen oxide, soot, and methane (Lin, 2022). However, this reform will only concern the shipping sector's direct emissions (Lin, 2022). Despite this significant reform, the EU ETS emissions coverage should be expanded to include the fossil fuels supply chains and other gases, especially methane in the cap (Monciatti et al., 2021). This process might require considerable methodological challenges to track all the supply chain emissions of the several EU ETS countries' exporters (Monciatti et al., 2021). Furthermore, methane is treated differently than other greenhouse gases due to its difficult quantification (Kleinberg, 2024). Indeed, most methane emissions are intermittent and of variable duration, varying in magnitude and intensity (Kleinberg, 2024). Another point worth making is that the pricing of supply chain methane emissions could generate a byproduct. Indeed, the inclusion of these emissions in the EU ETS might not generate a certain positive effect on emissions reduction (Chaudhuri, 2015). On the contrary, it could disincentivize natural gas or crude oil suppliers to increase their equipment maintenance since producing these two inputs becomes increasingly expensive (Chaudhuri, 2015). This could represent a significant issue since supply chain methane emissions mostly originate from leaks and losses of equipment or pipelines (IEA, 2020).

Despite these challenges, tracking methane along the supply chain remains a pivotal measure to significantly reduce emissions, especially from oil and gas operations in the power sector of the EU ETS (IEA, 2023). Indeed, according to the International Energy Agency (2023), cutting methane emissions from these supply chains might have the same effect on the global temperature rise as eliminating the GHG emissions from all the world's cars, trucks, buses and two- and three-wheelers (IEA, 2023). The demand function in the previous section represents an example of how the Italian firm's choice shifted from natural gas, being at first the most imported and used fossil fuel, to crude oil after the introduction of methane emissions along their supply chains in the cap-and-trade scheme, especially when EUA prices are expected to rise in the future (Fjellheim, 2024). Despite crude oil not representing the cleanest fossil fuel, its supply chain methane emissions are significantly fewer than those of natural gas and thus is an environmentally and economically favourable choice. This is to suggest that the introduction of methane emissions along the supply chains of all the firms regardless of the sector, might represent a low-hanging fruit for the EU ETS to largely reduce greenhouse gas emissions and meet its mitigation and decarbonization goals. Furthermore, this reform could help firms to identify the leader and laggard suppliers in terms of sustainability performance, and thus guide them towards the most significant emission reductions-product procurement and development (The Carbon Trust, 2024). Moreover, this introduction in the EU ETS might encourage more investment in low-carbon technologies and create a visible change among the participating sectors (The Carbon Trust, 2024).

To conclude, the introduction of supply chain methane emissions in the EU ETS might also encourage firms to rely more on renewable sources. Fossil fuels, especially natural gas, are used the most because they are cheaper than renewable sources (*Renewable and solar energy vs fossil fuels*, 2020). However, once the supply chain methane emissions are counted and priced in the EU ETS, natural gas does not represent the most economically convenient choice (Ministry of the Environment and Renewable Energy, 2023). As for crude oil, despite its supply chain emissions being lower, it remains an expensive fossil fuel when burned (IEA, 2021). Thus, this might encourage firms to use more renewable sources since the price difference would be reduced. Furthermore, the future of the energy sector belongs to renewable sources because they are clean inputs and will never run out (*Renewable and solar energy vs fossil fuels*, 2020). Meanwhile, the power sector and industries will rely on fossil fuels for another 50 years before they will completely run out. Thus, it is paramount for governments and policymakers to regulate their use in the most environmentally and economically efficient way possible (*Renewable and solar energy vs fossil fuels*, 2020).

Conclusion

This dissertation has sought to analyse the effectiveness of the European Union Emissions Trading System in meeting its emissions reduction and mitigation goals. Through a literature review and an economic approach based on the development of the demand function equation, this thesis highlighted that the EU ETS has not been effectively reducing greenhouse gas emissions. Indeed, the calculation of the natural gas and crude oil methane emissions from the Algerian supply chains to Italy has led this thesis to demonstrate that to fully accomplish its goals, the cap-and-trade scheme should include methane emissions in the cap, which represents a more potent pollutant compared to carbon dioxide (Glossary: Global-warming potential, 2023). Furthermore, this policy should also track the methane emissions along the fossil fuels' supply chains of the several industries within the EU ETS. This calculation provided an interesting result since it demonstrated that natural gas, the cleanest and most cost-efficient fossil fuel in power plants, has the highest number of methane emissions in its supply chain, compared to crude oil (Ministry of the Environment and Renewable Energy, 2023). Thus, this outcome could change the demand for these two inputs mix in the energy sector. However, it is worth noting that crude oil does not represent an environmentally and economically preferable choice but has a certainly less methane-emitting supply chain (Ministry of the Environment and Renewable Energy, 2023). The development of the equations in Section 3.9.2 of Chapter 3 confirms the importance of including methane emissions in the EU ETS by changing the permit prices of natural gas and crude oil and showing how the shift towards natural gas incentivizes its use and thus increases the number of methane emissions during its combustion and production.

Before proceeding with the conclusions, it is deemed necessary to underline some limits of this thesis. To begin with, tracking methane emissions still represents a blind spot in environmental research and the fight against climate change (Laconde, 2018). Indeed, significant work still needs to be done to reach reliable information and evaluation of these fugitive methane emissions. Therefore, the source consulted to calculate these emissions (Ministry of the Environment and Renewable Energy, 2023) might report some uncertainty related to the difficulty of tracking them. Indeed, fugitive methane emissions are intermittent and of variable duration (Kleinberg, 2024). Moreover, they mostly generate from accidents due to a faulty seal or leaking valve, and thus they are quite unpredictable since when they are tracked, they can vary significantly from being both overestimated and underestimated (IEA, 2020; Komodromos, 2023).

Another limitation encountered during this dissertation is the lack of information about the change in the structure of the European Union Emissions Trading System. Indeed, the current system does not include the calculation of methane emissions along the supply chain of the firms with the cap-and-trade scheme. However, a similar implementation will be launched in 2026 by the EU ETS, namely the EU's Carbon Border Adjustment Mechanism (CBAM), a tariff on carbon-intensive goods imported from abroad (EU Emissions Trading System, 2021). As mentioned in Section 2.5.1 of Chapter 2, this new system will put a price on the carbon emitted during the production of carbon-intensive goods entering the EU. This will help to encourage cleaner industrial production in non-EU countries (EU Emissions Trading System, 2021). Nonetheless, the price will be applied only to CO2 emissions during the production of these carbon-intensive goods. But as mentioned above, the major greenhouse gas emitted during the supply chain of fossil fuels is methane, especially along the natural gas supply chain (US EPA, 2024).

For this reason, it is paramount for researchers, governments, and non-governmental organizations to reduce these uncertainties and the related climate and economic risks (Laconde, 2018). The role of investment in advanced technologies might accelerate the reporting of fugitive methane emissions and overcome the issue of unreliable and unavailable data (Komodromos, 2023). Furthermore, the collaboration of the facilities responsible for methane emissions is pivotal (Laconde, 2018). Tracking the fugitive methane emissions from the several EU and extra-EU supply chains of the firms within the European Union Emissions Trading System represents a great challenge. Indeed, these latter companies must have access to concrete and reliable emissions data from their supply chain networks to identify and thus prioritize the areas for emissions reduction efforts and make them more efficient and aligned with the sustainability goals (Komodromos, 2023).

In conclusion, in a time when environmental sustainability has become an imperative rather than a trend, the European Union Emissions Trading System should adapt and change its structure to take more concrete steps towards emissions reduction and decarbonisation. Climate change and global warming have been increasingly threatening the Earth’s ecosystems by putting in danger hundreds of species and human beings’ health and lives. Three out of nine planetary boundaries have already been crossed, namely climate change, biodiversity loss and interference with the nitrogen and phosphorus cycle (Rockström et al., 2009; Steffen et al., 2015; Costanza et al., 2015). Thus, based on these final observations, governments, policymakers, and the population as a whole need to urgently take action to tackle the issues of global warming and climate change threats. A collective effort is paramount to build a more sustainable future for the current and future generations.

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