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Carbon pricing to fight climate change

A case study of France

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Abbreviations

CDR	Carbon dioxide removal
CCE	Climate-Energy Contribution
CH4	Methane
CO2	Carbon dioxide
COP	Conference of the Parties
CSR	Corporate social responsibility
EC	European Commission
EEA	European Environment Agency
EU	European Union
EU-ETS	European Union Emissions Trading Scheme
EUR	Euros (currency)
GDP	Gros domestic product
GHG	Greenhouse gases
INSEE	*Institut national de la statistique et des études économiques*
IPCC	Intergovernmental Panel on Climate Change
LMM	Linear mixed model
LTECV	*Loi n° 2015-992 du 17 août 2015 relative à la transition énergétique pour la croissance verte*
NGO	Non-governmental organization
NDC	Nationally determined contributions

OECD	Organisation for Economic Co-operation and Development
OFCE	*Observatoire français des conjonctures économiques*
PPM	Parts per million (unit of measure)
PPP	Polluter-pays principle
SLR	Sea-level rise
SRM	Solar radiation management
TFEU	Treaty on the Functioning of the European Union
TGAP	*Taxe Générale sur les Activités Polluantes*
TICC	*Taxe intérieure de consommation sur le charbon*
TICGN	*Taxe Intérieure de consommation sur le Gaz Naturel*
TICPE	*Taxe intérieure de consommation sur les produits énergétiques*
TOE	Tonnes of oil equivalent
UN	United Nations
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNGA	United Nations General Assembly
UNSD	United Nations Statistics Division
USD	United States dollars (currency)
WTO	World Trade Organisation

Abstract

It is acknowledged by most of the international community that climate change is one of the worst crises that humanity is facing nowadays. As countries keep making pledges to reduce the carbon emissions that led to global warming, carbon pricing has emerged as a cost-effective way to achieve these targets, since they turn these baneful emissions into a new commodity with a price equivalent to the cost imposed on the environment for that pollution. However, setting this price has proven to be difficult, as it needs to balance the required price to achieve ambitious mitigation goals, but also a price that is publicly accepted and not seen as unfair.

This study focuses on presenting the general framework for carbon pricing as a climate change mitigation strategy, making especial reference to the case of France, where the combination of different carbon pricing mechanisms prompted several conflicts, particularly arisen by those mechanisms leading to different carbon prices. The research will attempt to econometrically assess whether the introduction of these carbon pricing mechanisms in France has led to lowered emissions since their implementation.

Key words: Climate Change; Climate Change Mitigation; Carbon Pricing; Emissions Trading; Carbon Taxation; EU-ETS; Carbon Pricing in France.

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I. Introduction

A. Research topic

Citizens all over the world have had different kinds of concerns during the last few decades. Some concerns only affected a part of them, such as local armed conflicts – even if their cruelty towards those citizens should had preoccupied the rest of the continents. Nevertheless, others have concerned people at a global scale, such as generalised economic crisis, or more recently, the SARS-CoV-2 pandemic, which has hardly left any country out of the battle against it.

In this last block of global concerns, one has remained a constant for quite a long time, ever since its first signs started to show up, and it is climate change. In January 2021, while Europe was being hit by the third wave of the health crisis, the Copernicus Climate Change Service, the European climate observing program dependant on the European Commission (EC), reported that 2020 was the warmest year on record for the old continent, and that CO2 emissions continued to rise (Copernicus Climate Change Service, 2021).

Before introducing more about the subject of climate change, it would be useful to establish the distinction between to concepts that are usually blended together that, even if they are interrelated, should be differentiated: *climate change* and *global warming*.

On the one hand, *climate change* is the long-term change in the average weather patterns that have come to define the local, regional, and global climates of the Earth (National Geographic Encyclopaedia, 2019). The planet has over 4.5 billion years of history, and its climate has not always remained constant. Yet, when we talk about climate change, we primarily refer to the one that the Earth has been undergoing since the beginning of the industrial revolution in the 19th century, caused by increased human activity. Hence the difference with previous variations.

On the other hand, *global warming* is used to define the long-term increase of the Earth's temperatures, all around the globe, due to certain gases, such as carbon dioxide (CO_2) or methane (CH_4), known as greenhouse gases (GHG), being trapped in the air masses surrounding the planet and preventing heat from escaping back to the space (National Geographic Encyclopaedia, 2019), especially the warming relative to the period 1850–1900. This increase in the average temperatures can have devastating effects on life as we know it and it is the major driver of climate change. Therefore, the terms are often used interchangeably, but the latter only refers to the warming produced by humans.

Since the climate change issue was put on the table, it has been the subject of multiple international panels and discussion forums. Different options have been regarded as strategies to slow down uncontrolled climate change, but there is international consensus on reducing carbon, and more generally GHG, emissions, being the best strategy. Moreover, while reducing emissions can be done through different techniques, one has been favoured above the rest: carbon pricing.

Carbon pricing consists essentially in turning carbon emissions into a commodity, attaching a price to them, although they never had one before. In fact, the cost of carbon emissions has not been born by those who emitted them but imposed on humanity through accelerated climate change. With carbon pricing, once emitters fully internalise emission costs, they are incentivised to reduce them. The internalisation is possible through two different techniques, emissions trading schemes, and carbon taxes. In this research paper, the role of both on reducing emissions will be assessed through an econometric case study of France's carbon pricing mechanisms.

B. Research structure

To fully understand the importance of climate change and its role in current societies, this research paper is structured in three major blocks. The first one consists of an introduction to the subject of climate change and global warming. It presents its origin, and the consequences of disregarding climate change as one of the major threats for life on the Earth. As natural sciences prevail in the beginning, other disciplines, such as economic sciences or engineering sciences take the role further down this block, as they become essential, not to understand climate change, but to fight it off, through the different approaches on dealing with it.

As these approaches are presented in the previous block, mitigation strategies take precedence, being carbon pricing the most favoured policy. Accordingly, the second block analyses carbon pricing in depth, illustrating on its economic and legal basis, and pinning down the two most relevant carbon pricing mechanisms. Besides, a comparison on the advantages and disadvantages of each is made, and a brief display of the current spread of these mechanisms worldwide is shown.

Once the fundamentals of carbon pricing mechanisms are clear, the third and final block consists of a case study of France, a country whose story with carbon taxes illustrates on the difficulties policymakers must deal with, to successfully implement carbon taxes within its borders. In particular, because it is a context in which different carbon pricing mechanisms co-exist, each with a different carbon price, and the creation of exemptions can attempt against the principle of tax fairness. Firstly, the current status of France's carbon emissions will be seen in broad strokes, to understand the magnitude of their emissions problem. Subsequently, each carbon pricing mechanism in France will be analysed separately and on different levels to judge on the effectivity of carbon pricing to reduce carbon emissions.

C. Methodology

The methodology that will be used to cast a light on the efficacy of each carbon pricing mechanism to reduce carbon emissions in France will be a combination of statistical science with other disciplines, such as legal sciences, natural sciences, chemistry, or engineering, and with other disciplines as economics in many different aspects, such as climate economics, macroeconomics and econometrics, since carbon pricing mechanisms are economic tools.

However, our approach will be characterized by the predominance of statistical analysis applied to economics, therefore, econometrics, an analysis performed using RStudio. In this sense, the other disciplines only provide additional interpretative support for the econometric focus and they will be useful to understand the reports, datasets, and academic articles when they become too technical for general knowledge on climate change and carbon emissions.

In base of this methodology, the datasets on carbon emissions for France and French companies subject to the European Union Emissions Trading Scheme, besides those on the evolution of the carbon price for each, will be analysed. Once we have a general idea of how both carbon pricing mechanisms have evolved since their implementation, emissions trading and the carbon tax in France will be statistically examined.

The final objective of this work is to provide some clarity on our doubts regarding the suitability of current carbon pricing mechanisms as a mean of fighting climate change, but also that people who read this research paper are encouraged to delve more deeply in the topic of climate change and in the need to price carbon emissions to reduce them, as it is an issue that requires the compromise of through and across societies.

II. Climate change and global warming

A. The origin of climate change

It is commonly accepted that climate change is one of the major threats that humanity is currently facing. Other serious crises have proved to be short-lived compared to the long period of time through which climate change effects will extend. Economic crisis, wars, and even pandemics tend to follow the same path: the emergence of the issue, the development of the conflict, the process of the introduction of measures to fight it off, and eventually, the arrival of its end.

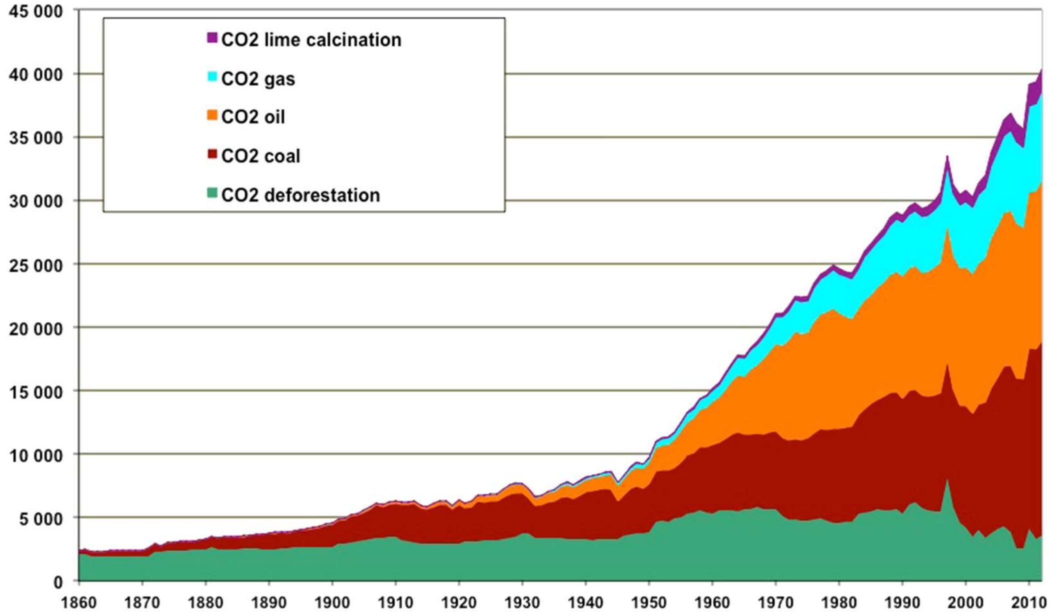
If its consequences on the population were negligible – which, of course, are not, due to the numerous casualties that are produced during them -, the main take away from crises is that a solution eventually arrives. With climate change, it is not so obvious. Moreover, if in the previous examples, one can wait until the rise of the crisis to work on a solution – the implementation of economic reforms, the finding of a vaccine or the establishment of multilateral panels –, that is not the case with climate change.

As it was seen before, the climate change that is of our concern is the one that gathers the changes experienced since the early 20th century, due to increased human activities during the second industrial revolution occurred worldwide, even if the first signs of global warming date as far back as in the 1830s in some regions (Abram, 2016).

Out of these human activities, the ultimate and most noteworthy source of global warming is the burning of fossil fuels, such as coal, oil, or natural gas. It leads to emissions of CO2, as shown in Figure 1, a type of GHGs that accumulates in the atmosphere and that prevents the heat emitted by the Earth from escaping back to the space, further contributing to the rise of the average surface temperature of the planet.

Figure 1

Evolution of worldwide CO2 emissions by source since 1860, in million tonnes



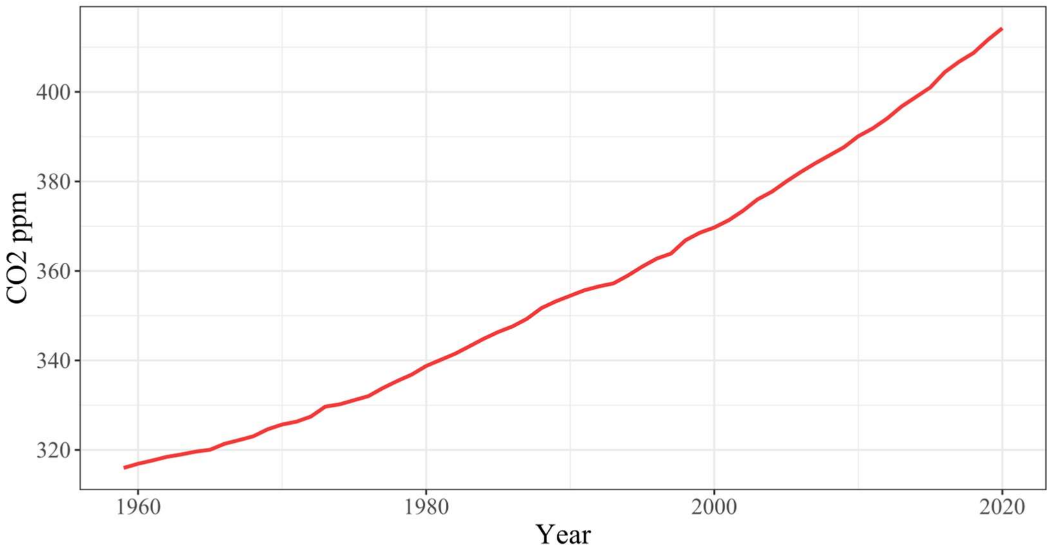
Note. There was an exponential increase in CO2 emissions during the 20th century, especially after the Second World War. Source: Jancovici (2013).

CO2 concentrations in the atmosphere are measured in parts per million (ppm). The level of concentration is determined by the imbalance between carbon sequestration – e.g., by its burial in sediments, or the capture by plants –, and carbon emissions – e.g., by the burning of fossil fuels, rock weathering or volcanic activity –. The imbalances create trends that affect global temperatures, and thanks to the modern-day study of the ice cores, it is possible to draw approximate values for past trends in concentration.

While there are no direct measurements of CO2 concentration levels from the pre-industrial era, there is general agreement on pre-industrial CO2 concentrations of around 280 ppm (Wigley, 1983). Moreover, looking further back into the data extracted from ice caps, through the several interglacial and glacial periods that the Earth has experimented in the last 800,000 years, CO2 concentration levels were never higher than 300 ppm (Lüthi *et al.*, 2008). At present, despite the seasonal cycles that affect monthly averages, the levels have not gone below 400 ppm since 2015, as it can be seen in Figure 2.

Figure 2

Trend in atmospheric CO2 concentrations from 1959 to present, recorded by the Mauna Loa Observatory, in parts per million



Note. CO2 concentration levels have experienced an exponential growth during the second part of the 20th century. The Mauna Loa Observatory provides the longest record of direct measurements of CO2 in the atmosphere. Source: Global Monitoring Laboratory.

Unless strong steps are taken, concentration levels reaching 700 – 800 ppm by the end of this century, as estimated by models considering current growth, could translate into an average temperature warming of 1.7 – 5.4 ºC by the year 2100 (Backlund *et al.*, 2008).

Gradually, international efforts have aimed at establishing a temperature target to limit the effects of climate change. In 1992, the United Nations Framework Convention on Climate Change (UNFCCC) was adopted, in which its Article 2 only required the “stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system”.

After the celebration of the Copenhagen Climate Change Conference in 2009 – the 15th Conference of the Parties (COP) to the UNFCCC-, the international community agreed on limiting the global temperature rise to below 2 °C above pre-industrial levels. Yet, lack of unanimous recognition by all parties of the Copenhagen Accord led to the 2 ºC target not being legally binding (Gao *et al.*, 2017).

However, it was only following the celebration of the Paris Climate Change Conference in 2015 – COP 21 to the UNFCCC – that the temperature target of 2 ºC achieved a legally-binding status, encouraging parties of the Paris Agreement to hold the “increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change” (Article 2 a)).

Resulting from the COP 21, the Intergovernmental Panel on Climate Change (IPCC), released a special report (2018) regarding this target, in which among its results, it found that there were evidently “clear benefits to keeping warming to 1.5ºC rather than 2ºC or higher” (p. v). For that matter, “limiting warming to 1.5ºC can go hand in hand with achieving other global goals such as the Sustainable Development Agenda” (p. vi).

Therefore, in terms of climate change, the temperature targets can be linked with the United Nations General Assembly (UNGA) *Resolution 70/1*, which lays down “a plan of action for people, planet and prosperity”. It contains the aforementioned Sustainable Development Agenda, also known as Agenda 2030, in which seventeen Sustainable Development Goals are laid out, along with one-hundred sixty-nine targets to achieve sustainable development, among others, in an environmental dimension (Díaz, 2016). The main SDG in the field of climate change is Goal 13, which aims at taking “urgent action to combat climate change and its impacts”.

However, while most mitigation options consisting of limiting the temperature rise below 1.5ºC will show, not only strong synergies with Goal 13, but also those related to health (Goal 3), clean energy (Goal 7), cities and communities (Goal 11), or oceans (Goal 14), the United Nations Environment Programme (UNEP) has found (2019) that, even if the Paris Agreement's commitments are effectively implemented, temperatures are predicted to rise by 3.2 ºC. Furthermore, they have estimated that it would be necessary to cut global GHG emissions by 7.6 per cent every year between 2020 and 2030, to not miss the opportunity of reaching the 1.5 ºC Paris Agreement goal. Yet, for 2020, despite the global pandemic and the reduction of human activity, estimations for GHG emission reductions are below 6%, according to the United Nations Statistics Division (UNSD).

In any case, an important take away of these climate actions particularly focused on temperature targets are that concerns regarding this warming are not due to the temperature rise per se, but the devastating effects an increase of such degrees will have on human life and natural systems.

B. The consequences of uncontrolled climate change

When addressing the consequences of climate change, we are no longer assessing the changes that have already taken place but forecasting the impact that the continuity of these changes will have on humans and other living systems.

Before starting with the study of the forecasted impacts, a difference should be established between managed and natural systems, in which the impacts of climate change will take place. *Managed systems* are generally defined as those with substantial human inputs, in which societies could take steps to ensure a sustainable use of the resource. Namely, agriculture or indoor living, as they can fairly be adapted to new climate conditions. *Natural systems* are, on the other hand, unmanaged, either because humans choose not to intervene, or because they are too large to be controlled. For instance, the sea-level rise or extreme natural phenomena (Rosenzweig *et al.*, 2007).

The distinction between managed and unmanaged is not trivial. Placing each system of our concern in a spectrum that goes from extensively managed to unmanageable helps to understand which areas should be of the greatest concern when it comes to climate change, in contrast to those where humans might be able to adapt to, despite requiring costlier technologies and measures (Nordhaus, 2015).

An area of great concern is agriculture and farming, as it is the most sensitive to climate. The idea is that the economic impact of temperature increases is likely to be small, as technological developments eventually take place in the sector and a lesser part of the population relies economically on agriculture (Rosenzweig and Parry, 1994). However, the further we go into the future, the more uncertainties regarding the impacts on food production arise, which is worrying because it is strictly related to human health issues due to global warming, such as malnutrition.

Uncontrolled climate change also has the potential to affect human health in other areas, such as an increase of diarrheal diseases and the spread of diseases such as malaria (Wright *et al.*, 2021). Still, these impacts are likely to be over-dimensioned, as the degree of improvement of health technologies is unforeseeable. Just as in agriculture, the impacts are likely to be unfavourable if they are particularly not properly managed.

The real concerns of climate change are focused in four major unmanageable threats, closer to natural systems than managed ones: sea-level rise (SLR), ocean acidification, hurricane intensification, and ecosystem losses (Nordhaus, 2015). Not only because they are unmanageable, but also because an economic assessment of their impacts makes us give a certain a price on the loss of human life, biodiversity or on forced migration, consequences of climate change (Roca, 2018).

SLR is the most worrying because the rise affects the whole globe and it is difficult to stop once it has started – even if policies are enforced from now on, some SLR is expected to happen due to current rising and its inertia. Economic losses might be small, but they might still affect precious human and natural heritages. Countries therefore will have to choose between retreating due to SLR or defending themselves from SLR (Bosello *et al.*, 2007).

Ocean acidification, on the other hand, is not the result of higher temperatures, but of higher carbon concentrations in the atmosphere. Part of that carbon is absorbed by the oceans, but it makes the ocean more acidic, lowering concentrations of calcium carbonate, and affecting marine organisms that live in the upper layers of the ocean and biologically rely on calcium carbonate. The ocean acidification has the potential to affect the distribution of marine species, and upon humans, it is likely to affect our fishing habitudes (Nordhaus, 2015).

Climate change also has the potential to affect the intensity of hurricanes. They are formed when warm moist water over ocean waters rises, is replaced by cooler air, which in turn is warmed up as well. This continuous replacement of air masses forms storm clouds, which, using the spin of the Earth, increase the speed of the cycle and end up forming hurricanes. Hotter oceans will create more favourable scenarios for hurricanes to arise, and while the effects on the coastal areas where they strike are predictable through models, the economic impacts of increased hurricane intensity will depend on the ability of human life to adapt to them (Nordhaus, 2015).

The last of the four largest unmanageable threats of global warming is the loss of biodiversity. Five mass extinctions have already taken place in pre-human eras. Biologists now agree that we have entered the beginning of a sixth mass extinction, in which about 75% of the planet species will be lost (Briggs, 2017). It is estimated that current extinction rates are 1,000 times higher than the natural background rate, and future rates are likely to be 10,000 times higher (De Vos, 2014). As biodiversity is a nonmarket good, estimating the impact of climate change is economically difficult, but as we put a price on extinguishing life, it also becomes a moral issue not any easier to solve.

In conclusion, climate change and global warming are serious issues humans all over the globe are facing nowadays, and as long as they have the potential to negatively affect us to the extent we have seen *supra*, it is easy to understand something has to be done to slow the effects down as much as possible.

C. Economic approach to climate change

Climate change and global warming are environmental phenomena. That is the reason why its impact is researched by environmental scientists, or why the evolution of the global temperatures and the CO2 concentration levels are studied by atmospheric scientists, like chemists and physicists. Yet, the present research is not the first in an economic field that deals with climate change, nor will be the last. It is important to understand the reason why.

The subject of climate change needs the involvement of natural sciences, which are essential to understand why it occurs and to determine the pace and regional dimensions of change. However, global warming begins and ends with human activities. Consequently, even if we cannot expect to understand the implications of the warming itself without the findings and overviews provided by earth scientists, social sciences are required to intervene once it is understood that economic activities are the primary source of climate change.

As a consequence, behavioural scientists are useful to understand the behavioural patterns of individuals, and to draw ideas on how to disincentivise these harmful behaviours. For instance, taxing the undesired behaviours has proved, most of the time, useful to discourage them (Yakobi *et al.*, 2020). Once the behaviours are identified and are tackled, the drawing of integral economic policies is necessary, requiring economists to draw economic models to integrate these policies and make estimations on the expected evolution of patterns, to assess the necessity of new measures. Therefore, the combined efforts of earth scientists and economists are suitable.

Nevertheless, climate change is not a crisis that can be solved through individual efforts alone. To slow the pace and to eventually prevent climate change, it is required to have effective, enforceable climate laws. Likewise, these laws must be adhered by most of the international community, although this proves to be difficult to achieve through current international agreements, with vague goals, inexistant pathways, and yet, the possibility of withdrawing at will.

Effective policy must be global, include mechanisms to encourage participation and discourage free riding - as mitigation action costs are high, incentives for smaller regions to free ride on the commitments of larger ones emerge (Perdana and Tyers, 2020). The discipline of Law finds its role in this flank of the battle. In fact, since the Kyoto Protocol was agreed in 1997, a twenty-fold increase in climate laws and policies has produced, going from around 60 to over 1,200 in early 2017 (Nachmany *et al.*, 2017). Even besides international commitments, legally binding measures adopted by countries require a legal document to express their will to involve all their citizens.

In these pages, some of these mechanisms, such as the adoption of unilateral acts to fight the effects of climate change, will be reviewed. In particular, the adoption of environmental taxes, to levy the emissions of GHG by companies and households, or the creation of markets where allowances to emit carbon are bought and sold.

D. Addressing climate change

As the consequences of climate change were examined, it has come as obvious that the world in which we live today is expected to change in the future. About these changes, we have the certainty about them happening, as their realisation obeys to scientific ground rules. Nevertheless, these changes are not predictable, since it is very difficult to know the exact moment in the future in which they will take place.

Acting on climate is one of the most urgent issues humanity must deal with nowadays. Yet, as the most dramatic changes seem likely to be happening with a certain margin of time, three different approaches appeared on how to deal with climate change: adaptation, geoengineering, and mitigation.

i. Adaptation

The first approach to deal with the future impacts of climate change is adaptation. It essentially consists of learning to cope with the higher temperatures worldwide, as part of the expert opinion considers that it is easier to learn to live with the changes rather than spending large amounts of money to prevent the effects of global warming (Nordhaus, 2015).

Technically, the IPCC (2018) defines *adaptation* as a "process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate, avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects" (p. 1758). These adjustments can be extended to the many assets that sustain us: agriculture, water-management, infrastructures, transport, etc. However, adaptation presents some drawbacks that are worth considering.

Firstly, while the economic sacrifice of reducing emissions might seem a priori larger, adaptation is not costless, especially for small islands and low-income countries (International Monetary Fund, 2019). Money will need to be invested to improve land management in agriculture, develop water storage and conservation techniques in water management, relocate cities threatened by SLR, or realign roads, railways, and other infrastructures. And while some adaptation options could be implemented in some sectors at low-cost, comprehensive estimates for global costs are limited, as the timeframe is extended further down the future.

Secondly, while prevention through the reduction of GHG emissions is global, adaptation is local, for a certain territory and group of people. The people that approve adapting measures bear with the costs of their implementation. Therefore, the capacity to adapt is intimately connected to social and economic development, which is unevenly distributed across and within societies (IPCC, 2007). For that reason, leaving all climate change issues to adaptation implies leaving countries that cannot afford adaptation behind, further widening the breach between the rich countries and poorer ones.

Hence, adaptation might be useful, or even necessary, in the future, to deal with some of the threats from a warmer world, especially in managed sectors, but it is a complement of mitigation (European Environment Agency, 2013), as in unmanaged sectors adaptation might realistically be impossible.

ii. Geoengineering

Geoengineering is the second approach to slow climate change, which consists of offsetting the warming due to GHG emissions with cooling devices. It has been defined by The Royal Society (2009) as the "deliberate large-scale manipulation of the planetary environment to counteract anthropogenic climate change" (p. 1). As efforts through international agreements to reduce carbon emissions have not fully worked and the 1.5 ºC target becomes more remote, the scientific community has become increasingly interested in the geoengineering approach (Reynolds, 2019). The geoengineering approach aims to intervene in the Earth's climate system modifying the planet's energy balance to reduce and stabilise the temperature at a level other than the current climate change pace leads us to.

The methods used are diverse but can be divided in two groups. On the one hand, carbon dioxide removal (CDR) methods, which aim to reduce the concentration of CO2 in the atmosphere, so that outgoing heat radiation can continue to escape. An example is ocean fertilisation, which involves reducing CO2 levels in the air by stimulating the photosynthesis of phytoplankton in the upper layer of the ocean. On the other hand, solar radiation management (SRM) methods, which aim to slow the increase on or reduce global temperatures by reflecting the sun's energy. One example is white roof methods and the brightening of human settlements, as a way to increase the reflectivity of the Earth's surface.

The drawbacks of geoengineering arise from the lack of experience with them. While geoengineering and weather modification proposals date as far as in the 19th century, no complete CDR o SRM technology yet exists, and no large-scale geoengineering experiments have been carried out. Cost estimates indicate that, if technologies happen to be prosperous, geoengineering would be much less expensive than reducing CO2 emissions. Yet, major issues of these technologies revolve around the ignorance of their effectiveness and the possible side effects (Nordhaus, 2015).

Furthermore, the existence of geoengineering also poses problems regarding the potential of these technologies to become climate warfare, as John von Neumann

(1955), founder of game theory, already remarked in the 1950s. Political problems caused by geoengineering can appear once a country engages in climate management technologies on their own, as a solution to a global problem cannot be imposed by one region. Any responsible geoengineering project will need to be negotiated at an international level, to kick them off, but also to prepare a compensation scheme for regions affected by the side effects of the geoengineering technologies (e.g., decrease in precipitation), to be 'made whole' again (Heyward, 2014). Therefore, in terms of international relations, geoengineering might be just as difficult as a mitigation approach.

The uncertainties regarding geoengineering are not small, but experts remark that these should not encourage us to directly dismiss it (Leal-Arcas and Filis-Yelaghotis, 2012). Continuing research and experience with technologies can help us understand the methods, and they could be included as a part of a wider portfolio of responses to approach the climate change issue, together with adaptation efforts and mitigation. Geoengineering should not be regarded as the solution to climate change but be presented as an emergency 'handbrake' to be implemented in exceptional cases. For that to work, climate communicators will also have to start an open debate with society members so that extreme depictions of these technologies do not rise problems in terms of potential moral hazards (Raimi *et al.*, 2019).

iii. Mitigation

Both adaptation and geoengineering as means to slow climate change propose approaches which do not come without some drawbacks. Whilst they are not fully satisfactory solutions for the threats that climate change poses, there is only one acceptable in the long run, which implies reversing the GHG concentrations in the atmosphere, and it is preventing climate change through mitigation.

Mitigation is the most favoured approach to deal with climate change, which essentially consists of reducing the GHG emissions that reinforce the global warming, being CO2 emissions the most important, but also other long-lived GHGs, like methane, and short-lived, like aerosols. The technical definition by the

IPCC (2018) is the "human intervention to reduce the sources or enhance the sinks of greenhouse gases" (p. 1769).

It is considered the safest approach because it aims at avoiding the gamble that climate change effects are – it does not wait until these are produced and we adapt to them, nor relies in potential-yet-inexistent technologies to deal with it in the future. As it has been discussed *supra*, the effects of climate change are certain in their realisation but uncertain in their extent. Estimates might be close to the real estimates, but there are factors, such as the existence of tipping points (Russill and Nyssa, 2009), that are not fully considered, and their exceeding might turn these effects irreversible, so avoiding these uncertainties is the shrewdest move.

Within climate change mitigation strategies, several approaches are considered to reduce GHG emissions: slowing overall growth of economies; reducing energy consumption; reducing carbon intensity of production of goods and services; and removing post-combustion carbon emissions from the atmosphere. Again, each presents some disadvantages.

As a matter of fact, causing a recession can reduce carbon emissions and benefit the environment, but it is not recommended for the price to be paid, as it reduces the growth on other dimensions, such as health, that are just as important for human life. And carbon capture and sequestration, that is, capturing CO2 through technologies at the time of combustion and ship it off somewhere before it enters the atmosphere, is technologically feasible, yet economically difficult and controversial, due to the process of sequestration being expensive, and the transport and storage process posing safety and health problems if leakage is produced (Nordhaus, 2015).

In any case, there is international agreement on the need to reduce emissions. After the Paris Agreement, 190 parties submitted "Nationally Determined Contributions" (NDC), unilateral commitments on reducing GHG emissions. However, these pledges are heterogenous (in terms of targets, stringency, or baseline years for reduction targets), insufficient to meet temperature targets, and might only have limited impacts for the largest emitters (International Monetary Fund, 2019).

Consequently, it is still necessary that all countries participate equally in the mitigation strategies for them to work. However, countries are made up of societies, which in turn are made of individuals. Individual choices are, therefore, the source of the increase or decrease on emissions from a certain region. Economic history has shown us that market mechanisms are a useful tool to affect individual decisions, and the one that is missing nowadays to encourage the behaviour of individuals to reduce emissions is a widely spread carbon pricing mechanism.

III. Fighting global warming through carbon pricing

The idea behind carbon pricing is that economic incentives are essential for individuals to change their consumption habits. As for now, in many of the world regions, carbon emissions have no costs for those responsible for them, even though they evidently impose a cost on society through the worsening of climate change. These costs are not reflected in prices and consumers do not have an incentive to choose among low-carbon options, because there are many fields in which they are not easy to identify (namely, food options), or they just simply do not want to bear the higher prices of low-carbon options, as cheaper higher-carbon options are available.

Carbon pricing, as a mitigation mechanism to reduce GHG emissions worldwide, relies on the basis that once the costs of carbon emissions are integrated in consumer prices, carbon-intensive goods will be emphasised in the eyes of the consumer, as they will rapidly increase the prices of these, compared to other low-carbon goods. Moreover, higher-carbon options will fairly compete with low-carbon goods in terms of final prices, so companies will be encouraged to reduce the emissions in their production processes to continue offering competitive prices (Branzini *et al.*, 2017). In the following pages, emissions trading schemes and carbon taxes will be presented as carbon pricing mechanisms.

A. Fundamentals of carbon pricing

Carbon pricing consists fundamentally in putting a price on carbon emissions, as it can be interfered from its name. This technique to internalise the costs of carbon emissions that are normally not reflected in the prices of products can be justified both from an economic and a legal perspective.

i. Economic basis: externalities

The GHG issue is a case of a market failure. *Market failures* can be defined as the inefficient allocation of resources in a free market, inefficiency that can be caused by a wide variety of reasons. One of them is the existence of negative externalities, in which costs are imposed to a third party. In our case, the real cost of climate change is imposed on humanity in general, while it should be held by those responsible of the carbon emissions. It is considered, by some, “the greatest example of market failure ever witnessed” (Stern, 2008, p. 1).

Ever since the industrial revolution began, companies have not born the full cost of their production, namely the environmental damages, and have imposed the costs that arise from pollution on society at large, as they could offset part of their costs with their externalisation through the pollution of air and water (Andrew, 2008). Through this method of cost abatement, human activities have already caused a global warming of an estimated 1.0 ºC (± 0.20 ºC) with respect to pre-industrial levels (IPCC, 2018). Keeping in mind the goal of maintaining the increase in temperatures below 1.5 ºC by around the year 2100, the concept of paying for carbon emissions from now on is not only fair, but also necessary, if the aforementioned wants to be achieved at the end of the century.

Society in general consumes the environment without having to compete with one another and at nil or little cost. As the environment is a commodity whose existence benefits everyone, people can enjoy the advantages of it without having to pay anything. But since it has shown an apparent abundance, an over-consumption of the environment has taken place. Pollution has been possible because the environment is a classic example of a public good. However, to deal with global public goods, like the environment, it is difficult to properly locate the decision making at a level that can efficiently coordinate solutions (Nordhaus, 2007).

Economic activities have been responsible of the over-consumption of the environment, but despite the apparent inexhaustible supply of it, society today is bearing with the long-term consequences of this – a free-of-charge over-consumption has proved to not be sustainable (Andrew, 2008). Since polluters benefit from not having to pay for the pollution, it is only economically sound that part of the profits of free pollution are returned to the authorities in charge of inspecting, controlling, and adopting measures to contain the pollution generated by those activities (De Sadeleer, 2012).

ii. Legal basis: polluter-pays principle

The desire of economic growth, combined with the fact that generating carbon emissions has turned out to be free ever since the industrial revolution began, has raised climate change as one of the most important challenges society is facing nowadays (Vinogradov and Soldatova, 2019). The polluter-pays principle (PPP) is one of the main principles of Environmental Law that tackles this issue, on the basis that as long as polluting does not have an attached cost to it, polluting will never stop.

The foundations of the relationship between humanity and the environment were first laid in during the 1972 United Nations (UN) Conference on the Environment in Stockholm (Sweden). The PPP was not featured in the Stockholm Declaration, but it was included in the *Rio Declaration*, adopted after the 1992 UN Conference on Environment and Development in Rio de Janeiro (Brazil). Its Principle 16 stated:

> National authorities should endeavour to promote the internalization of environmental costs and the use of economic instruments, taking into account the approach that the polluter should, in principle, bear the cost of pollution, with due regard to the public interest and without distorting international trade and investment.

Before the *Rio Declaration*, the Organisation for Economic Co-operation and Development (OECD) issued the *Recommendation of the Council on Guiding Principles concerning International Economic Aspects of Environmental Policies* of 26th May 1972, in which the PPP is mentioned for the first time. In the scope of the European Union (EU), the PPP is cited for the first time in the *Recommendation of the Council on the Implementation of the Polluter-Pays Principle* of 14th November 1974, as the EU included it in its first Environmental Action Program for the period 1973-1976.

It was not until 1987 that it was included for the first time in a legally binding instrument, the then *Treaty of the European Community*, and today the *Treaty on the Functioning of the European Union* (TFEU), in its article 191(2):

> Union policy on the environment shall aim at a high level of protection taking into account the diversity of situations in the various regions of the Union. It shall be based on the precautionary principle and on the principles that preventive action should be taken, that environmental damage should as a priority be rectified at source and *that the polluter should pay*.

The main function of the PPP is "to internalise the social costs borne by the public authorities for pollution prevention and control" (De Sadeleer, 2012, p. 408). However, it should be understood in a much broader sense: it has a preventive function, as the polluter is expected to reduce pollution as soon as the costs of polluting become higher than the benefits from continuing polluting; a control function, since the costs of monitoring pollution are also paid by the polluter; a punitive function, for the costs of cleaning-up the environment from future damage; and a reparative function, to cover the clean-up costs of damage that has already taken place (Salassa Boix, 2016).

Therefore, considering the case of carbon emissions, a case in which polluters have never born the full cost of polluting the environment, it is obvious that it is a field in which the PPP should find its application. Introducing carbon pricing, as a mean of incorporating the cost of the GHG emissions in the products of those generating them, is a mean of making the polluters pay.

B. Types of carbon pricing policies

Carbon pricing puts a price on carbon emissions to encourage their reduction and mitigate the effects of climate change. This tool is based on the economic and the legal grounds stated *supra*. However, carbon pricing is a broad term which encompasses two different mechanisms that allow to put that price on carbon emissions: emissions trading and carbon taxation.

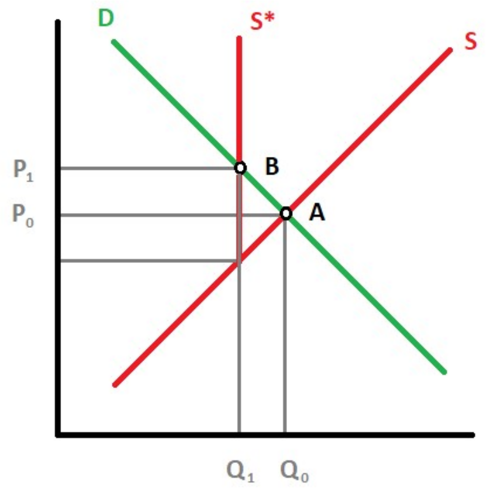
i. Emissions trading

Emissions trading offers a more liberal approach to carbon pricing. With it, authorities do not set a price for the emissions of carbon but a cap on the aggregate emissions level of a certain region. Therefore, it allows the market to determine the price of those emissions. To understand more intuitively how the mechanism works, we can study the graph below (Figure 3).

Before the introduction of the cap-and-trade scheme and a cap on the emissions, the carbon emissions equilibrium is Q_0, with a price of P_0. Nevertheless, officials, based on environmental studies, perceive this equilibrium as undesired, as Q_0 is over the maximal supply of pollution rights. Consequently, a cap is introduced, and the supply curve of carbon emissions becomes completely inelastic, as $S^* = Q_1$. In turn, setting this cap on the supply of carbon emissions changes the equilibrium price, reaching P_1, which generally should be higher than the previous P_0.

Figure 3

Effects of the introduction of a cap-and-trade scheme through a supply and demand curve graph



Note. The introduction of a cap in emissions automatically reduces the quantity of emissions (Q_1). If demand remains unchanged, the unaccounted externality costs of carbon emissions are internalised in the price (P_1).

While this mechanism relies on the market to establish the new equilibrium price P_1 after the cap is set, it is an effective system to reduce the pollution in our atmosphere. The cap on GHG establishes a solid limit on the emissions permitted for, ideally the whole economy, but normally, for given sectors, and as the limit gets stricter over time, authorities can adapt to achieve their decarbonisation goals or pledges made towards the international community.

The total amount of the cap is split into allowances, which permits the agent that possesses one of them to emit one tonne of carbon emissions. These allowances can be distributed among companies through auctions or for free. Nevertheless, since the cap is meant to be reduced over time and carbon prices are expected to increase, it provides economic agents with incentives to efficiently reduce their emissions, so that they are able to keep production costs low.

Once companies have their allowances for a certain period, three different scenarios are possible: the possessed allowances might match the emissions emitted, and there would not be any problem; or they might not match, either because one is emitting a quantity of tonnes higher than the allowances they had allocated, either because the number of tonnes emitted is lower than the previously allocated. In these cases, the *trade* from the cap-and-trade comes into play.

Agents, typically companies, have the possibility to resort to a carbon market to match their emissions and allowances. Cap-and-trade is a system favoured by many because it is considered that, not only companies are encouraged to comply with the allowances, but also inspires them to further reduce their emissions because they know that they have the possibility of selling the unused allowances and make a profit out of them (Zweifel *et al.*, 2017).

The improvements in technologies will be carried out by companies that consider the reduction of carbon emissions economically sensible (e.g., the profit of introducing improvements and selling the allowances is higher than continue emitting and using up the possessed allowances). The result of the cap-and-trade mechanism is the achievement of carbon emissions reduction with the minimum cost.

However, there is an alternative to cap-and-trade as a carbon pricing policy to be able to include households, which also emit a considerable amount of carbon emissions through road transport and residential heating and are hard to include in cap-and-trade, and it is carbon taxation.

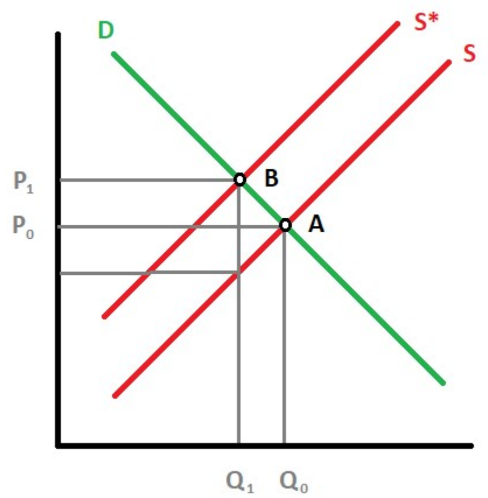
ii. Carbon taxation

Carbon taxes are levies imposed generally on the burning of fossil fuels, aimed at reducing and eventually eliminating the use of these energy sources whose combustion is responsible for destabilising and destroying our climate. Governments can set a carbon tax in terms of monetary units per tonne of GHG emitted, or a tax in proportion to the carbon content of the three main fossil fuels (coal, petroleum, and natural gal) as they enter the economy (International Monetary Fund, 2012).

The tax needs to be cost-effective, that is, it should cover all sources of carbon emissions, and it needs to be efficient, setting a tax price equal to the marginal cost of the reduction in emissions (Murray and Rivers, 2015). It is also important that, over time, the carbon tax increases, as the more GHG accumulate in the atmosphere, the greater the incremental damage of one more tonne of CO2 is. The effects of a carbon tax on the demand and supply curves are seen below in Figure 4.

Figure 4

Effects of the introduction of a carbon tax through a supply and demand curve graph



Note. The introduction of a carbon tax increases prices to the same extent of its value (P_1), although not capping for carbon emissions. If demand remains unchanged, the higher prices lead to lower emission levels (Q_1). It is a case of upstream taxation (suppliers).

The introduction of a tax, from a macroeconomic perspective, has different effects depending on whether it consists in upstream or downstream taxation. If it taxes refineries and importers of petroleum products, the supply curve is shifted to the left, as for the same price P, less carbon-intensive products will be offered. Whereas if final emitters are bearing the weight of the tax, the shock is on the demand curve, shifting it, therefore, to the left, as disposable incomes are affected and for the same price, less carbon-intensive goods will be acquired. In both cases, Q is reduced, going from Q_0 to Q_1, even if impacts in prices are different. Ideally, the tax should be applied upstream (International Monetary Fund, 2012).

The idea is that, just as in the cap-and-trade, the price of carbon-intensive goods, that is, the products intensive in those sources of energy, but also the fossil fuels themselves, raises, causing consumption to decrease. Therefore, carbon emissions are also expected to decrease, but without certainty on the extent of the reduction. As the tax gradually increases, it is also expected to lead to both overall energy savings and investments in energy-efficiency technologies, while switching consumption to goods that are less carbon-intensive, e.g., deciding to switch from a combustion-engine vehicle to hybrid or electrical options.

As countries end up implementing a carbon tax, they attach a price to carbon emissions that rarely matches that of other countries (e.g., France introduced its carbon price in 2014 at EUR 7 per tonne of CO2, while Sweden's was over EUR 100 for the same year). A phasing of the tax, with the prevision of increases gradually, can be, nevertheless, a good strategy for enhancing acceptability of the tax. It offers an opportunity for households and companies to adapt to the tax, as prices of consumer goods adjust steadily to their carbon content and the economic agents have time to improve their consumption choices according to the new price signals.

The average price for emissions worldwide is about USD 2 per tonne, which is certainly below of what is needed, but it does not need to be significantly much higher. The International Monetary Fund has calculated that a USD 35 per tonne carbon tax might be sufficient for some countries to meet the Paris targets, although others need much higher prices (Parry, 2019).

An ideal scenario for a carbon tax should be a global tax, as climate change is a global issue. It could either be a global tax collected by an international organisation, or a harmonised tax for all the countries. However, this is far from the current possibilities. Therefore, so far, there are only examples of national-level carbon taxes, although only a few, as countries are normally reluctant to adopt carbon taxation (Padilla and Roca, 2004).

Besides the fact that adopting a tax is a difficult political decision, countries are concerned about the loss of competitiveness in international trade due to increased prices of carbon-intensive products affected by the tax (International Monetary Fund, 2012). Aside from the political obstacle that constitute firms fearing being outcompeted, the risk of carbon leakage, meaning the situation in which a company, due to the costs related to climate policies, decides to transfer production to laxer-emission-constraints countries, also threatens the implementation of taxes at a national level (Burniaux and Oliveira Martins, 2012).

However, there are mechanisms to ameliorate these problems, such as carbon border taxes, which levies imported products with a tax equivalent to the emissions that the domestic production of those would have generated (Roca, 2018). It is a difficult task yet introducing carbon border taxes would allow the implementation of a carbon tax. For instance, the EU is already in works to adopt an EU carbon border adjustment mechanism, complicated because it could fall into contradiction with the World Trade Organisation (WTO) agreements, but that would facilitate the implementation of carbon taxes among Member States.

C. Advantages and disadvantages of emissions trading and carbon taxation

Carbon pricing is essential to alter the behaviour of economic agents in order to reduce GHG emissions, and it can easily be perceived that both emissions trading and carbon taxing are effective means. Certain territories, such as the EU, have chosen the implementation of emissions trading schemes (ETS) over the introduction of a general carbon tax across Member States, while other regions, such as Canada, France, or Sweden, opted for carbon taxation. Each option is valid yet offers different advantages and disadvantages. In this section, these will combinedly be assessed, as usually the weaknesses of one can be made up for with the other, and vice versa.

In terms of achieving reduction targets, cap-and-trade is viewed by some, like the EC (2015) as "*the best means of meeting a GHG reduction target at least overall cost to participants and the economy as a whole*" (p. 5). In fact, the existence of a tax on carbon emissions might not guarantee that reduction target, if economic agents are still willing to pay its price and consider paying for the pollution more economically desirable than the introduction of low-carbon technologies in their production processes, or than the change in consumption patterns. With cap-and-trade, there is, therefore, certainty about the quantity of GHG emissions. By setting a cap, compliance with reduction commitments is ensured, as long as important sanctions are expected by those exceeding it.

On the price of emissions, another upside of the cap-and-trade before a carbon tax is that the possibility of trading should naturally set the right carbon price, as it is especially difficult to determine the right price of the tax for that cut in emissions to be produced, besides setting the adequate increase path for that tax. Setting a carbon price through a tax is risky, as it can lack sufficient theoretical basis, and affect unequally economic agents, under- or overcharging them. However, a carbon tax provides certainty about the marginal cost of complying with the emission reductions, which in cap-and-trade depends on a given market price, even though, as it was said earlier, left uncertainty about the economy-wide emission levels.

While carbon pricing is mainly an economic tool to incentivise the behaviour of agents to reduce carbon emissions, one cannot forget about the extra revenue that they offer to collectors. Even if it should be kept in mind that carbon pricing is not exclusively aimed at increasing general budgets, and that revenues are expected to decrease for both policies in the long run (as emissions decrease and economies become more decarbonised), these revenues can be used to fund measures to fight climate change.

However, the revenue from a carbon tax is unlimited, as carbon emissions are not capped, and a carbon tax can be applied to tax both households and companies. In ETS, the revenue comes mainly from the initial actioning of the emissions allowances, which are gradually reduced, and only companies are normally subject to cap-and-trade, so the revenue is limited compared to carbon taxation. Furthermore, unlike international ETS, carbon taxes enable to keep the tax payments within the country (Green *et al*., 2007).

Moreover, as a carbon tax is introduced by a country, in contrast to ETS, a wider catalogue of policy options is available for the adopters. Part of this revenue should be used to compensate the poorest households, for which bearing the burden of the tax is more arduous, to reassure that the carbon tax is as revenue neutral as possible. However, the remaining part is expected to go to the countries' general budgets, and it can be used efficiently and transparently to secure the social acceptability of the carbon tax. For instance, to compensate revenue tax or corporate tax reductions.

Its implementation should also be considered. A carbon tax could be easily implemented in most countries, as long as they have effective tax systems already in place, with monitoring and enforcement regimes to minimise tax evasion. Since monitoring can be done through the estimations of the emissions that would result from the combustion of the fossil fuels, the implementation would be straightforward. Pre-existing collection mechanisms at any territorial level could work for carbon taxes.

The same cannot be said for ETS, as they require creating new trading markets on which emissions permits will be traded, with special regulations and specific institutions to supervise their functioning. For small regions, introducing an ETS is typically nor economically nor practically feasible, despite examples of ETS in territorial units smaller than a country, such as the Regional Greenhouse Gas Initiative and California's cap-and-trade program, in the Unites States (Calel and Dechezleprêtre, 2016).

Likewise, in terms of creating incentives, putting a price on carbon emissions through a carbon tax that levies the consumption of fuel can be more effective than the existence of an ETS. As prices of fuel increase through a tax, the rise in prices would spread more widely all thorough the economy, increasing prices of consumption goods other than strictly energy-related products.

On one side, consumers would be more incentivised to buy local products, to change their means of transport, to insulate better their homes or to care more about the energy efficiency of their domestic appliances, to save up money on consumption. On the other, manufacturers would be encouraged to opt for more efficient technologies, to reduce costs of production and continue to offer competitive prices in the market.

In any case, since it is called carbon *pricing*, the price is the most delicate issue. Going back to it, a carbon tax also offers an opportunity to price carbon in a stable way. As records from the European Union Emissions Trading Scheme (EU-ETS) market have shown, the carbon price in these markets can fluctuate easily. The volatility has been affected by factors such as the distribution of free allowances or the future expectations on the market being short. On the other hand, a carbon tax not only would offer predictability on the carbon price for economic agents, as it was seen earlier, but stronger price signals (Green *et al*., 2007).

The summary of this section is, therefore, that while both ETS and carbon taxes are useful carbon pricing techniques, the advantages of carbon taxes are considered to outweigh those of the difficult-to-implement ETS. Some authors consider that relying on the market to reduce carbon emissions through an ETS to solve the market failure that constitutes climate change "would be the triumph of hope over experience" (Andrew, 2008, p. 393).

Above all, general optimism about the future implementation of carbon taxes worldwide, rather than ETS, relies on another fact: countries general budget outlooks in the long-term are not the greatest and new fiscal measures will need to be introduced eventually to make up for greater expenses. The introduction of a carbon tax justifying it in the need to cut emissions to meet reduction targets will be easier to accept that any other increase in current taxes directly affecting households and companies, but it will nevertheless be useful to easily increase national tax incomes.

D. Current development of carbon pricing policies worldwide

In the world today, one can find examples for both cap-and-trade and carbon taxes, implemented in different countries or regions as carbon pricing mechanisms. Along the following pages, European examples for both mechanisms will be reviewed, to see how the theoretical principles behind carbon pricing seen above are applied in the real life.

Regarding cap-and-trade, this theoretical model has also been put in practise, being the EU-ETS the most noteworthy experience. It caps the total volume of GHG emissions from certain installations and aircraft operators that are responsible for approximately 50% of the EU GHG emissions, covering over 11,000 power stations and industrial plants in 31 countries, and flights between airports from participating countries (EC, 2015).

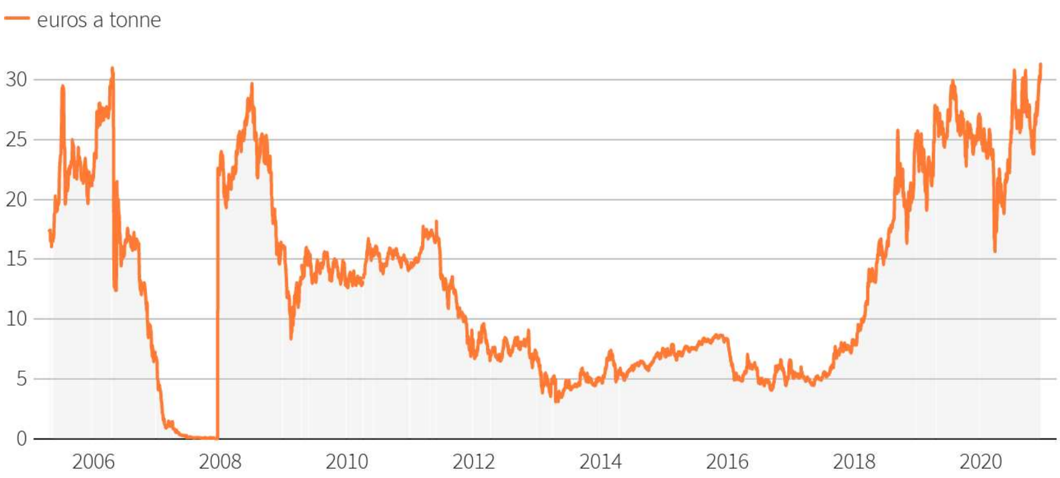
In 1997, after the Kyoto Protocol was agreed, the EU-ETS started to take shape. As the Protocol set legally binding GHG reduction targets, the EU needed new policy instruments to meet these commitments. Accordingly, the EU adopted the *Directive 2003/87/EC of the European Parliament and of the Council, of 13 October 2003, establishing a scheme for greenhouse gas emission allowance trading within the Community*.

It proposed the implementation of the cap-and-trade scheme through the division into distinct trading periods over time, also known as phases, to ensure correct functioning of the ETS. The first phase, which ran from 2005 to 2007, was the pilot phase, used to test price formation in the carbon market and to observe which was the necessary infrastructure. The second phase ran from 2008 to 2012, which overlapped with the first commitment period under the Kyoto Protocol, and with the expansion by the inclusion of the aviation sector as the most remarkable benchmark. A third phase ran from 2013 to 2020, which was shaped by the lessons learnt from the previous two phases. Up from January 2021, a fourth phase was introduced, with the most stringent caps so far, resulting in the carbon prices in the EU-ETS hitting new all-time highs (S&P Global, 2021).

A remarkable irregularity took place from mid-2006 until the end of the first phase, where prices dropped to EUR 0 per tonne (Figure 5). Until April 2006, market participants had the belief that the market would be short at the end, meaning companies would have to pay a penalty if they could not come up with enough emission rights. Yet this was not the case, as emissions in 2005 were lower than the allowances, and the European Commission announced that these could be used until the end of the first phase, so overallocation of permits led to prices going down (Green *et al.*, 2007). This irregularity shows that cap expectations for market participants are relevant in terms of price formation.

Figure 5

Evolution of the carbon price in the European Union Emissions Trading Scheme, in euros/tCO2



Note. Despite the earlier irregularities in the carbon price formation, particularly the drop around after 2006, in the last few years the price has grown sufficiently to consider the stringent caps on emissions fulfilling their goal. Source: Reuters (2020).

Expert opinions on the effectiveness of this cap-and-trade system vastly differ. One of the aspects that is debated about the EU-ETS is whether it effectively fulfils its function of signalling on emitters the need of reducing carbon emissions. As seen from the historic prices (Figure 5), the market has not been able to ensure carbon prices were high enough to force energy generation from coal out of the market for most of its existence. However, other economists remind that the EU-ETS's main purpose was to reach ambitious reductions on emissions at the lowest cost, and since targets have been met, the system can be characterised as rather successful (Ma, 2013).

For this mechanism to continue functioning well, it is necessary that the principle of capping remains respected. Moreover, if authorities wish for a higher CO2 price, they should send signals to the market making agents believe that the market will be short on allowances by the end of the then-current trading period, namely, through the introduction of more ambitious targets (Friedrich *et al.*, 2019).

While cap-and-trade is effective to reduce carbon emissions, it is difficult to implement at an only national level, since the infrastructure behind these schemes is nor simple nor cheap. That is one of the reasons why the EU, with an international dimension, could opt for it. When it comes to cut down emissions at a national level, countries normally choose carbon taxes. Even in Europe, where the EU-ETS is in force, Member States have introduced several carbon taxes, as the carbon emissions covered by the EU-ETS only account for around 50% of the total EU emissions, and Europe aims to be an economy with net-zero GHG emissions by 2050 (International Monetary Fund, 2020).

The forerunners of carbon taxing in Europe are, as usually happens with environmental issues, the Nordic countries. In 1990, Finland became the first country in the world to introduce a carbon tax. Despite its low carbon price, only EUR 1.12 per tonne of CO2, it still became the first to adopt fiscal measures to attempt to reduce carbon emissions as a mean of mitigating climate change, even before the celebration of the Rio Earth Summit of 1992, where the issue of global warming started to become a serious subject (Nachmany *et al.*, 2015).

Still, one of the most famous cases of success in the implementation of a carbon tax is the case of Sweden. It was introduced for the first time in 1991, pricing carbon emissions at around EUR 24 per tonne, and it gradually increased until a price for emissions in 2021 close to EUR 114 (Government Offices of Sweden, 2021), being currently one of the highest carbon taxes in the world (Andersson, 2019). Economic growth has generally been linked with increased GHG emissions. Yet the success of this case comes from the fact that Sweden has been able to combine a reduction on GHG emissions with economic growth, as during the 1990-2013 period, the country's gross domestic product (GDP) grew by 61% but emissions shrank by 23% (Åkerfeldt and Hammar, 2015).

What is even more interesting is the stability of the tax during the experience of the last 30 years, merged with lack of significant public opposition, without the revenues generated by the carbon tax affected to particular climate purposes, contributing directly to the Swedish general budget (Government Offices of Sweden, 2021). According to them, the key factors that supported public acceptance were general environmental concerns, both from households and firms; broad political consensus as to ensure stability through government changes; ensuring that other feasible alternatives are possible, such as biofuels, public transport, or housing insulation mechanisms; and a step-by-step approach with limited exemptions or tax reductions for certain economic sectors (Sweden's Ministry of Finance, 2021).

The case of Sweden, even if it has not been without critics (Jonsson *et al*., 2020), can therefore be a good example for other countries to effectively implement a carbon tax, at least in terms of stability in the tax system. While most EU countries tax carbon emissions to some extent, not many do it by an officially called *carbon tax*. Other "carbon taxes" are established without directly affecting carbon emissions. Namely, Catalonia's regional "carbon tax", created by the *Llei 5/2017, de 28 de març*, which levies the fact of owning a vehicle that has the potential of generating carbon emissions, but not the emissions themselves (Article 85). Therefore, the objective of carbon taxes, which is reducing carbon emissions in a certain territory, is not fulfilled in this case.

In conclusion, successful carbon taxes examples provide evidence of their suitability to be implemented by countries as a mean of reducing carbon emissions, ensuring a price stability that is rarely seen in ETS, and can be adopted more easily than a ETS framework. However, since taxes are not normally welcome by those affected by them, the tasks in communicating them effectively are just as important as those dealing with the well-design of the tax.

IV. France as a case study of carbon pricing

Once this point has been reached, it is clear that climate change mitigation should be the most preferred approach to deal with nowadays anthropogenic global warming. Moreover, carbon pricing is the most adequate technique to effectively reduce carbon emissions, regardless of whether cap-and-trade or carbon taxation are used, despite the latest being more favoured.

To study how carbon pricing is adjusted to reality when implemented in a territory, the case of France will be assessed. Firstly, because it is a country that has adopted both cap-and-trade and carbon taxation as means to achieve a reduction in GHG emissions, through the subjection of part of the French companies to the EU-ETS, and through the introduction of a carbon tax in France's tax mix addressing explicitly carbon emissions. Secondly, because it is interesting to see how they evolved, as they both experienced important gaps in terms of the price of carbon emissions.

As merging both mechanisms can be particularly delicate because the subjects subject to each pricing mechanism are different, and the level of emissions is in fact dissimilar, each carbon pricing mechanism in France will be studied through two different methods, linking carbon emission reductions with carbon price evolution. Data for the EU-ETS dates as far back as for its creation in 2005, but for the French carbon tax only since its establishment in 2014. Therefore, for the first, the study will be focussed on the analysis of past data for the period 2005-2020, and for the carbon tax, on the analysis of data for the period 2010-2019, to see if there is any difference between the *ex-ante* and *ex-post* levels of emissions.

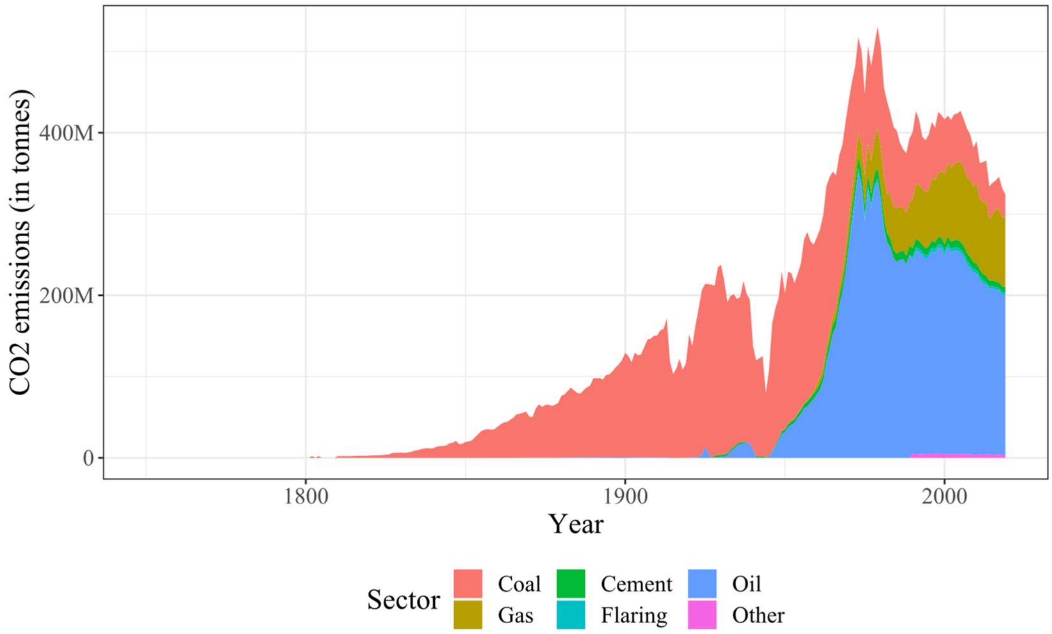
A. Country profile

Before the analysis of the carbon pricing mechanisms in France, it is advisable to assess how the carbon emissions profile of the country is. Despite it not being strictly necessary to proceed with the statistical evaluation of emissions, it can provide insights into the generation of emissions by sector and explain some of the results found later.

In terms of historical CO2 emissions, France has shared the same path of developed countries (Figure 6), exacerbated by the fact that France has taken part in most of the important occurrences of the last two centuries: while France experienced an early industrialisation in the 19th century, it was also involved in both the First (1914-1918) and Second (1939-1945) World Wars, and it was affected by other events, such as the Great Depression of 1929, and the Oil Crisis of 1973. During those incidents, emissions dropped, due to the economic recessions.

Figure 6

Evolution of France's CO2 emissions by fuel source since 1750, in million tonnes

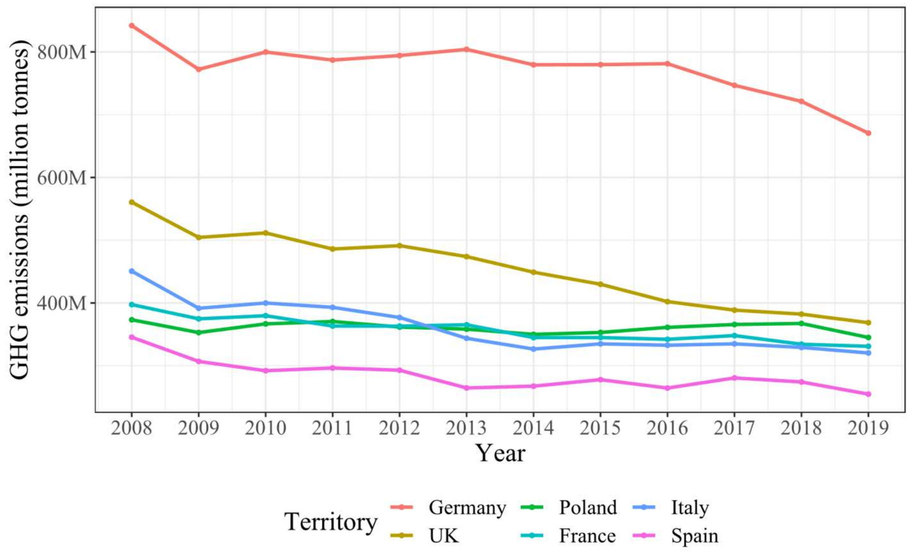


Note. The graph shows for France the exponential increase in CO2 emissions during the second half of the 20th century, leaving behind the economic losses from both the World Wars and the Great Depression. Source: Our world in Data.

France is also one of the biggest, in terms of population, and one of the wealthiest, in terms of GDP, countries in the European Union. It is, therefore, not surprising that it is one of the highest emitters of GHG among Member States in absolute numbers (Figure 7).

Figure 7

Evolution of emissions for the highest GHG emitters in the EU since 2008, in million tonnes



Note. France only falls behind Germany –by far, the highest GHG emitter in the EU–, the United Kingdom (Member State until 2020), and Poland. Source: Eurostat.

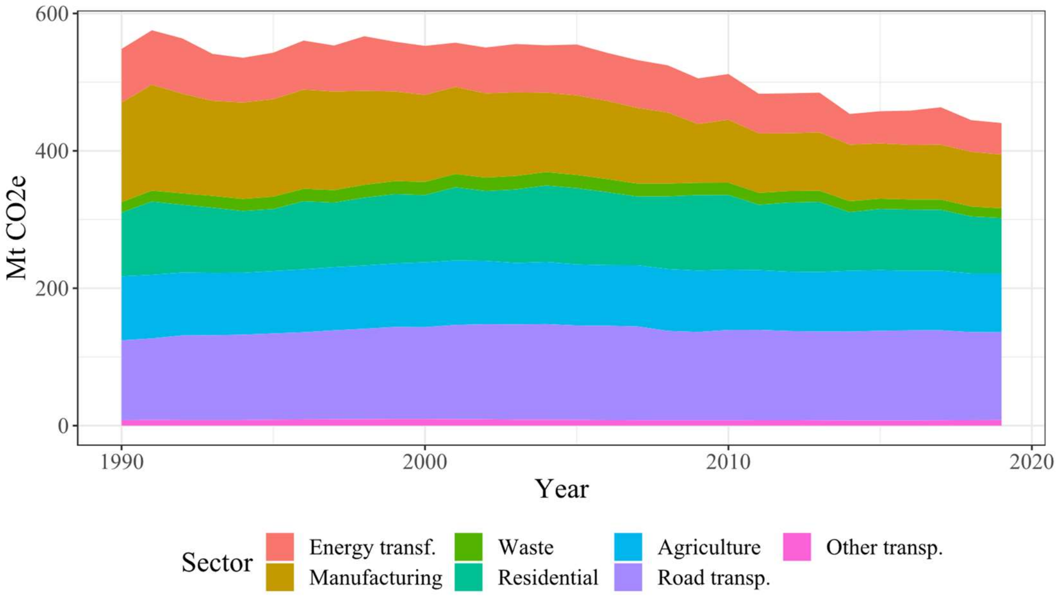
Despite its population and GDP, France is tied up on emissions with countries, such as Italy or Poland, with fewer habitants and lower GDPs. This is possible due to the type of energy mix France enjoys of. While renewable energy sources only account for around 15% of the total energy generation, nuclear energy generates over 70% of the total electricity supply in France. In fact, it is the second most nuclear country in the world, falling just behind the United States, and nuclear energy is a low-carbon source of energy, so the energy sector is already quite decarbonised, in comparison with neighbouring countries.

This is also reflected when analysing France's CO_2 emissions per sector (Figure 8), as emissions from energy transformation are lower than those of residential sources, mainly coming from households, or road transport, which still rely largely on fossil fuels, emissions which are more difficult to reduce. However, the reduction of CO_2

emissions in the manufacturing sector during the last few decades is remarkable, as it might hint the efforts of industries to decarbonise their production processes.

Figure 8

GHG emissions per sector in France since 1990, expressed in million metric tonnes of carbon dioxide equivalents (Mt CO2e)



Note. Despite overall lowering of GHG emissions during the last few decades, the residential sector, agriculture, and road transport have not shown any relevant changes in terms of emissions. Source: Institut national de la statistique et des études économiques (INSEE) (2021).

The tendency on the gradual fall of emissions reflects the fears of a country that has long been concerned about the environment. In fact, the earliest project of a fiscal instrument to mitigate climate change dates as early as 1990 (Laurent and Le Cacheux, 2009). It has had since 2004 an Environment Charter (*Charte de l'Environnement*), with constitutional value. With regard to other regulations, the Environmental Code (*Code de l'Environnement*), in its Article L 110-1 II 3, includes the PPP, in the following terms:

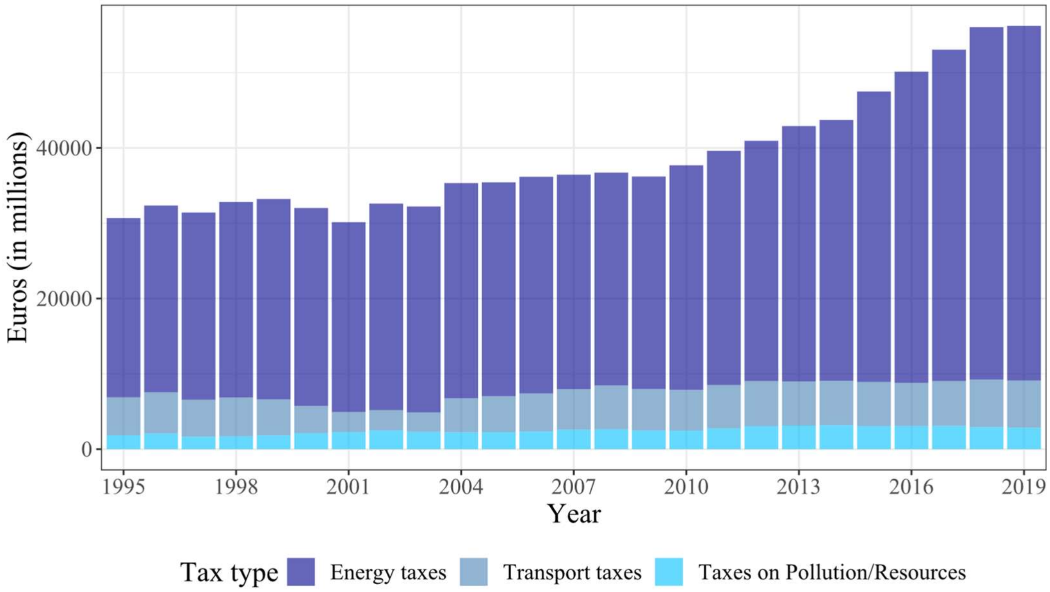
> [The protection, enhancement, preservation of the environment] are inspired, within the framework of the laws which define its scope, by the following principles: [...] The polluter pays principle, according to which

the costs resulting from pollution prevention, reduction and control measures must be borne by the polluter.

Within the scope of application of the PPP, environmental taxes have found its role as means of making the polluters pay for their damages. In fact, the revenues of these, applied on transport, pollution, and energy, have experienced an important increase during the last decade, especially energy taxes, which have nearly doubled compared to the 1990s revenues (Figure 9).

Figure 9

France's environmental tax revenues, for the 1995-2019 period, in million euros



Note. An important increase is seen after the year 2015, which coincides with the introduction of a significantly higher price on the carbon tax. Source: Eurostat.

All domestic energy taxes are considered environmental taxes in statistics, even though for France, only the carbon tax, as a part of the energy taxes, aims at reducing CO2 emissions (Gloriant, 2018). While only the revenue from a carbon tax, not the EU-ETS, would be reflected in Figure 9, France has experience both with emissions trading and carbon taxation, within a climate policy framework, aiming at decarbonising electricity generation.

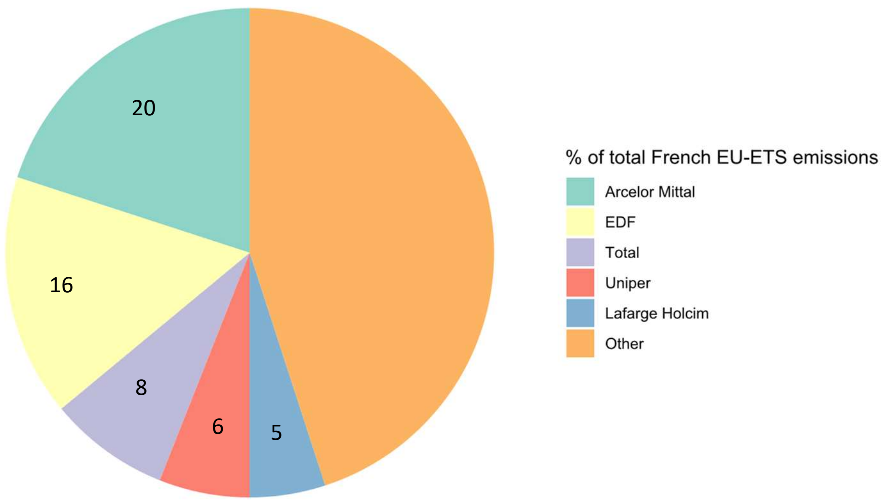
The country is currently employing the EU-ETS, in place since 2005 and covering 75% of total French industrial emissions, and a carbon tax on fossil fuel consumption, in place since 2014 and now amounting at around EUR 45 per tonne (Dussaux, 2020). In the next sections, both mechanisms will be described and will be analysed in the terms established earlier in this section.

B. French companies in the EU-ETS

The EU-ETS, as a cap-and-trade emissions market was briefly explained in Chapter III. France, since it is an EU Member State, also has some of its companies subject to the EU-ETS. Therefore, some of the French CO2 emissions were partly covered by a carbon price long before the introduction of a carbon tax in 2014 within the French borders. An important feature of these emissions is that, for most of the time that the ETS has been in place, the top five highest French emitters essentially implied around half of the covered emissions, as it can be seen in the figures below. Moreover, emissions covered from electricity generation sources are lower than the European average, due to the important role of nuclear in France.

Figure 10

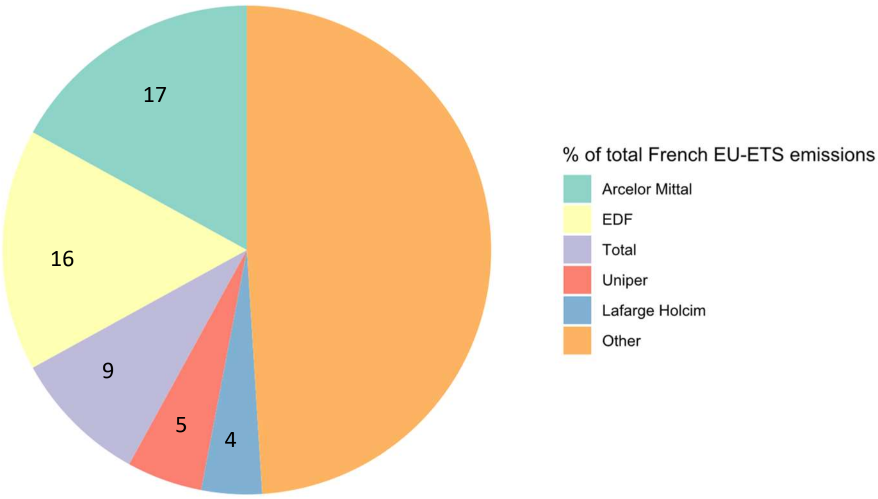
Top five highest emitting French companies for Phase 1 (2005-2007)



Note. For each company, the weight is expressed in percentage over the total covered French emissions. Source: EU transaction log (EC).

Figure 11

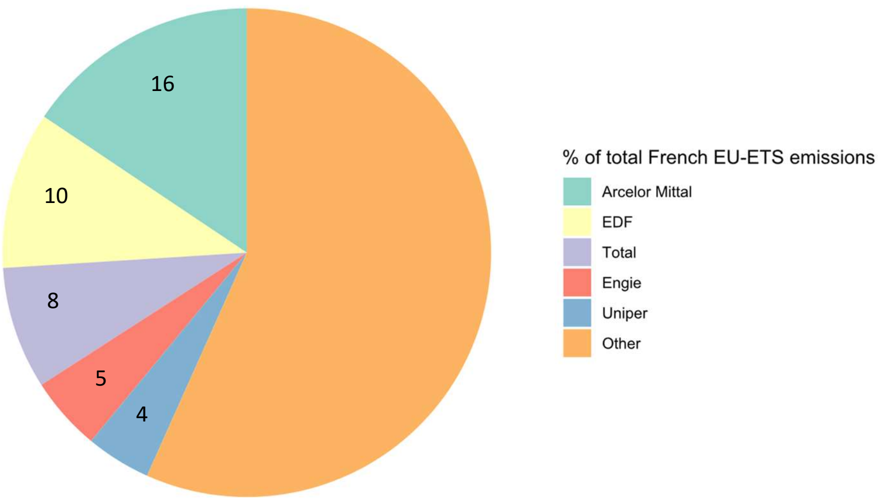
Top five highest emitting French companies for Phase 2 (2008-2012)



Note. As more companies are included in the EU-ETS during the Phase 2, the relative weight of the highest emitters is reduced, but companies remain the same. Source: EU transaction log (EC).

Figure 12

Top five highest emitting French companies for Phase 3 (only 2013-2015)



Note. Again, the relative weight of the highest emitters is reduced, *Engie* pushes out *LafargeHolcim* from the top five, but emissions remain highly concentrated. Source: EU transaction log (EC).

i. Analysis of the effects of the EU-ETS in France

In this section, we will attempt to analyse if the EU-ETS carbon price triggered any significant effects on the emissions for the eight highest emitting French companies, for which we have the yearly verified emissions for the period 2005-2020. This self-constructed data base merges the different installations of each company, for which yearly emissions are available in the EU Transaction Log of the EC. That is, for *Électricité de France* (EDF), it merges all the installations for which the *Account Holder Name* is "EDF SA", and so on for each of the eight companies.

These eight companies are, besides EDF, *Total*, the oil and gas multinational company; *ExxonMobil*, another oil and gas multinational; *Ciments Calcia*, a French company specialised in the concrete sector; *LafargeHolcim*, a building materials multinational manufacturer; the electric utility multinational *Engie*; *GazelEnergie*, the third largest energy producer in France; and *AcelorMittal*, the multinational steel manufacturing company. As a matter of fact, the eight companies belong to sectors notorious for their carbon-intense production processes.

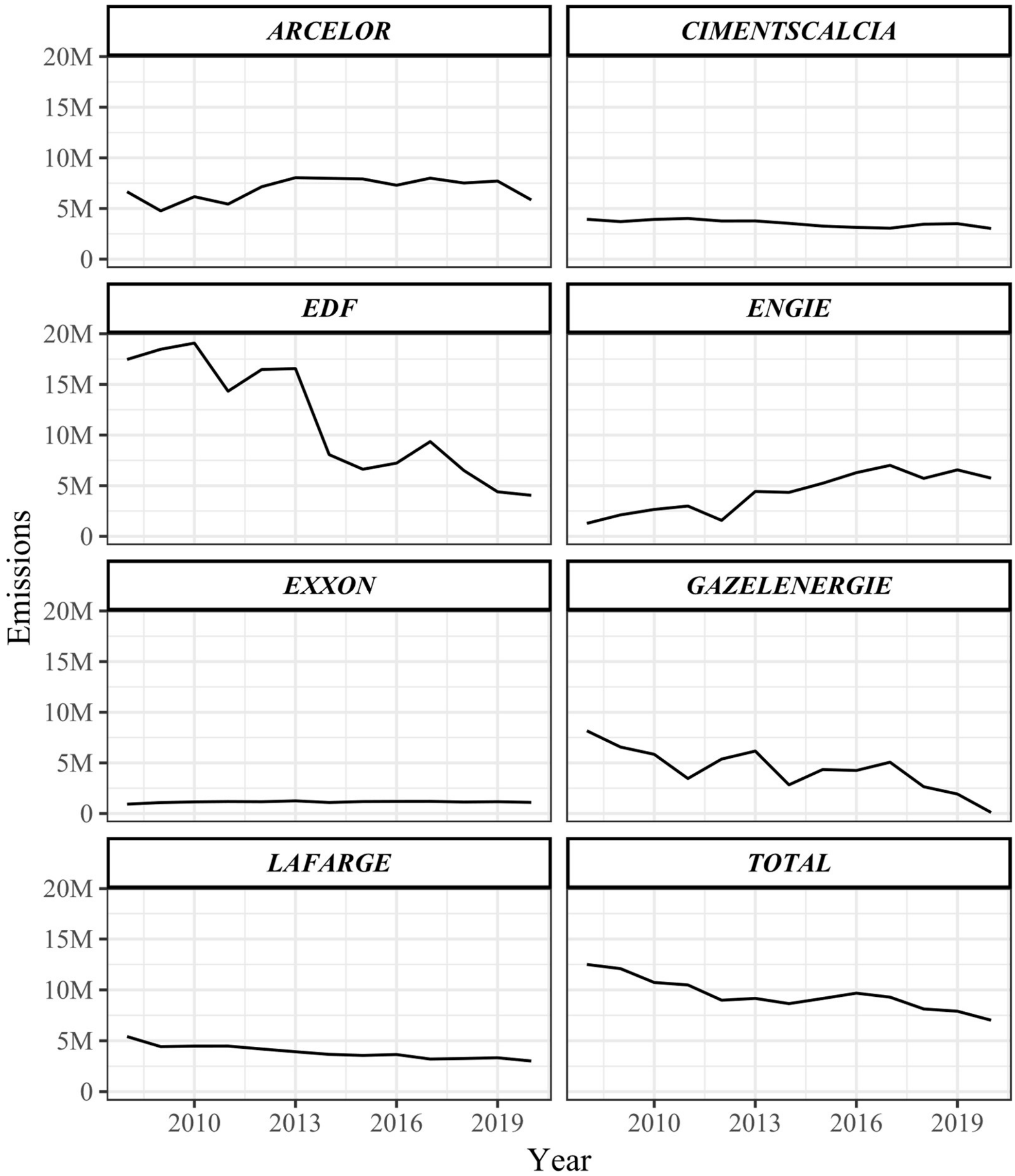
While there was already consolidated data for these companies for Phases 1 & 2 from reports released after the evaluation of these, we consider a trading period of eight years (2005 – 2012) not long enough to appreciate effects on emissions, particularly considering that it coincides with a very volatile period for the carbon price in the EU-ETS market. Using a trading period of sixteen years, therefore, includes data from all the three Phases that took place before the introduction of the fourth in 2021, and is more likely to provide interesting insights for our research.

As available data for emissions is disclosed in yearly intervals, but data for the EU-ETS carbon price is available for each trading day, our model uses the median yearly price for each year, to assess if there is any relationship between the trend on the price evolution and on the reduction of emissions, despite the oversimplification of this technique.

It also uses the median, instead of the yearly mean, to avoid outlier effects (e.g., an observation that represents an anomaly to the trend) on the price, which normally appear in financial markets. More accurately, in spite of outlier effects affecting the median, this is less liable to be distorted by outliers than the mean average. Future works will be advised on working with more specific periods of time for emissions, such as months, but also studying a longer period of time, that partly includes Phase 4, in which prices are expected to reach the highest levels since the introduction of the EU-ETS.

Figure 13

Yearly evolution in emissions for each company for the period 2008-2020, in million tonnes



Note. Despite sharing the "highest emitting French companies" title for absolute emission values, each shows a different trend on emissions, some decreasing, increasing, or remaining unchanged for the period of time examined. Source: EU transaction log (EC).

For our statistical model, our null hypothesis is there is no correlation between emissions emitted by a company and the price of the EU-ETS. The alternative hypothesis is there is correlation between the emissions of each company and the market carbon price. If we rejected the null hypothesis, it would imply there is some sort of relationship between the emissions of a given company and the carbon price set by the EU-ETS. As Figure 13 shows, a general overview of each company's emissions is not conclusive to assess any relationship, so we must proceed to carry out our model.

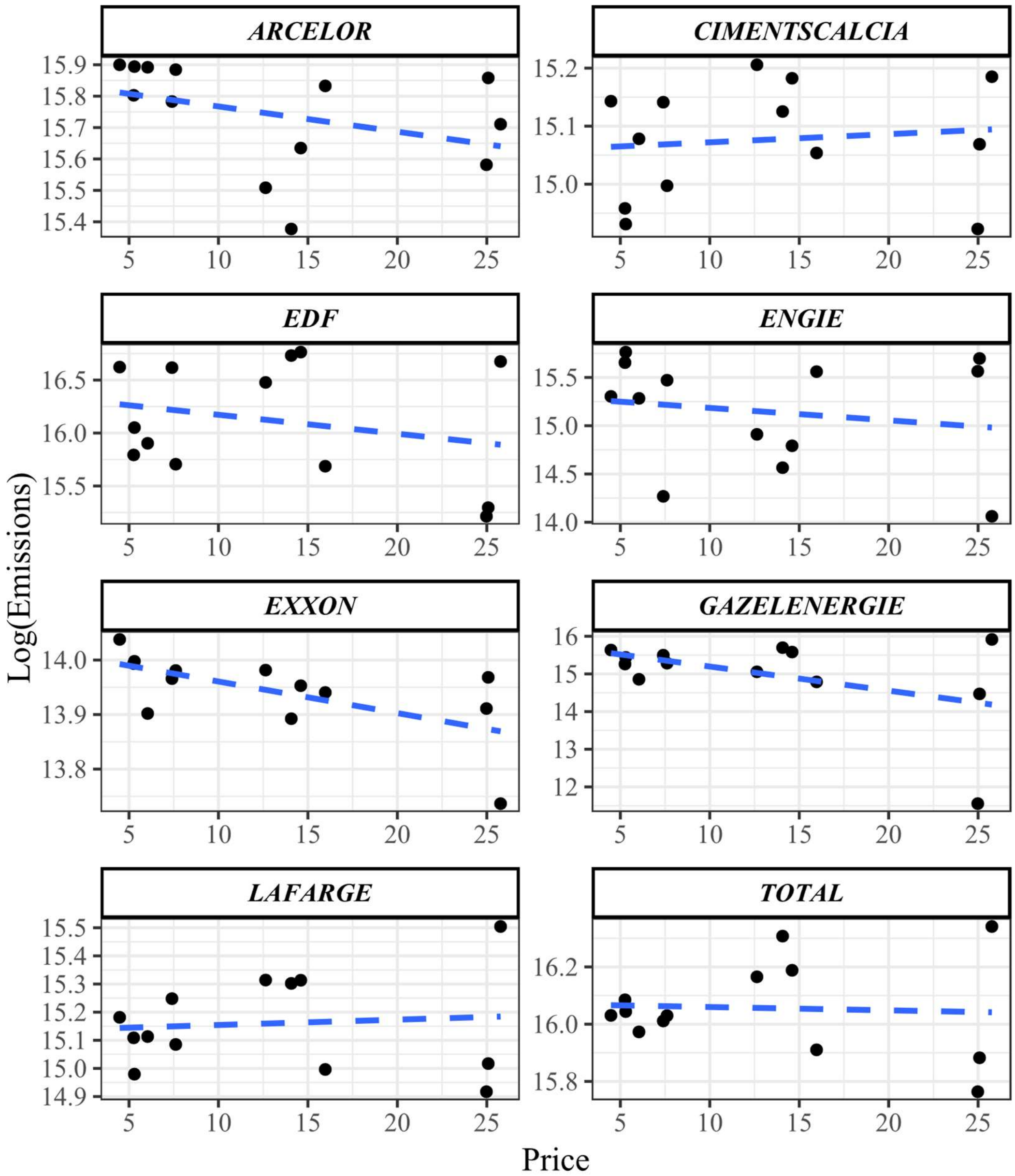
Using RStudio, we carry out a linear mixed model (LMM) as a method to analyse our data, which is considered to be non-independent or hierarchical, correlation which arises from the fact that each company has its own structure and is only capable of modifying their total carbon emissions to a certain extent. Since this hierarchical structure of our data is able to negatively affect the results of a simple linear model, we could either run individual regressions for each company, or aggregate our data taking averages, but both options would either be too noisy, or not take full advantage of having data for the eight different companies.

An LMM, as an extension of simple linear models, allows the incorporation of fixed and random effects, and in our case, lets us remove from the model the intrinsic variability for each company. Moreover, we apply a log transformation on emissions to make our data distribution less skewed. We use a significance level of 0.05, which indicates there is a 5% risk of concluding that the price effect on emissions exists when there is no actual effect.

The model specification was as follows: log(Emissions) ~ b0 + b1 * Price + (1|Company). The results from the LMM show there were significant effects of the EU-ETS price on carbon emissions for companies for a significance level of 5% ($b1 = -0.013322$, $t(95) = -2.13721$, $p = 0.0351$). It shows that there is an inverse correlation between EU-ETS carbon price, and the tonnes of CO_2 emitted by these companies subject to the EU cap-and-trade scheme. Therefore, the interpretation is that for every 1-unit increase in the *Price* variable, the *log(Emissions)* variable decreases by the beta coefficient value, that is, 0.013322.

Figure 14

Scatter plot and regression line between Price and log(Emissions) for each company

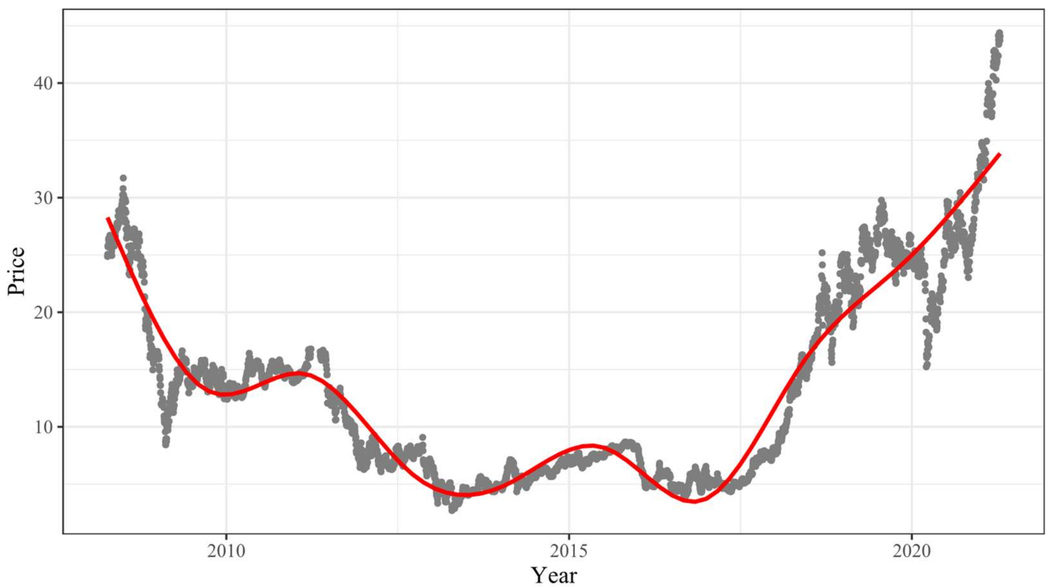


Note. While for most companies an increase in the carbon price leads to a decrease in the emissions, for others, such as *Ciments Calcia* or *Lafarge Holcim* emissions do not only not decrease, but increase.

Consequently, we might interfere from our model the existence of a price signal on emissions in the EU-ETS. If we attempted to study this for each company, the interference would be difficult to stop (Figure 14), just like if we only took a look at the trend on the carbon price (Figure 15). To effectively signal the negative externalities of carbon emissions, the price path should have followed a gradual increase for most of the life of the EU-ETS, which has not been the case.

Figure 15

Trend on EU-ETS price between April 2008 – April 2021



Note. An adequate price signal would have avoided the downfall in the price during the first two phases. Source:

Our conclusions for the analysis of the EU-ETS and the emissions of the aforementioned French companies are that, in spite of our findings, which have shown there is a significant relationship between the EU-ETS carbon price and the emissions, these should be handled carefully. Especially, after studying the evolution of the price for the period 2008 – 2013, in which the market carbon price did not only not increase to signal companies to reduce emissions, as an undesired output of their production processes, but it did indeed decrease, which does not make economic sense in such an environmental fiscal tool.

It is more than possible that companies decreased emissions due to other reasons, such as stronger national regulations, the wish to becoming certified by a certain ISO (accreditations awarded by the International Organization for Standardization which ensure certain standards of quality, among others), or just to improve their image in terms of corporate social responsibility (CSR) in face of the general population; not because they were specifically responding to a EU-ETS carbon price increase. However, it might be due to the price. We should interfere this from a more in-depth analysis of each company, which is not carried out in our study.

To complement our conclusions on the effects of the EU-ETS carbon price in the French industrial sector, it is interesting to remark that an OECD study of 2020 on the effects of energy prices and carbon taxes on environmental and economic performance found that, in the case of France, increased energy prices through the inclusion of carbon pricing not only did not lead to an industry level loss of full-time employees, but it effectively led to a reduction of energy use and a decrease in carbon emissions (Dussaux, 2020). Therefore, at a general industry level, the carbon price and emissions share the inverse correlation found in our model.

In any case, this market carbon price must be put next to the carbon price that the national French tax sets, which currently shares a similar price (of around EUR 45 per tonne of CO2), but this has not been the case for most of the experience with the European cap-and-trade mechanism. It is important to remember, when studying that, that, as stated by the OECD (2018), in 2015, France priced four fifths of industry emissions at effective carbon rates below EUR 30, which is very low. Not only that, but for most of the earliest years of the EU-ETS, allowances were handed in for free, so it is not actually fair to say French companies started paying for their carbon emissions as early as in 2005.

As a final conclusion, we consider that the inclusion of a border tax should have been proposed in the earliest steps of the ETS to avoid the price signal inefficiencies in the first years. Allowances would have not been handed in for free for nearly ten years for the companies that risked losing competitivity, which happened to be the highest emitters, and they would have been more solidly encouraged to reduce emissions. The pretext of protecting European industries from untaxed industries abroad is, in part, fair, and it is understandable since no one wishes to bear extra costs when others around you are not facing them, but, sadly, making them pay for their emissions with an appropriate carbon price as soon as possible is necessary *only* on the pretext of protecting our environment.

C. Carbon taxation in France

Carbon taxation is an alternative to price carbon when the implementation of an emissions trading scheme appears to be difficult, and it is one of the pillars needed to transition to low-carbon economies. As it was reviewed in Chapter III, the ideal situation for an effective pricing of carbon emissions would be an international harmonised carbon tax, so countries would not postpone the implementation of one due to local opposition from, not only households, but also from companies that fear a loss of competitivity when competing with untaxed products from abroad. However, since it seems difficult to achieve this kind of international agreement, some countries do not wait for this to happen to create a national-scoped tax on carbon.

France is not the only country in the EU with a tax on carbon emissions, nor the first. Nordic countries already started experimenting with them in the 1990s, whereas the earliest French attempt dates from the year 2000. Nevertheless, it is an interesting case due to the struggles France had to face to finally be able to implement it in 2014. Some of the issues with carbon taxes come from the creation of exemptions for companies, to protect their competitivity in the international field, or because they are already subjected to an ETS, as in the case of France.

In this section, firstly, the cases of the Ecotax (2000) and the Carbon Contribution (2009) will be reviewed, as they display these struggles in the history of France and carbon pricing. Both cases share the same faith: the invalidation of the projects by the *Conseil Constitutionnel*, France's constitutional court. Following this, the current Climate-Energy Contribution (2014) will be presented, and our analysis will attempt to assess the effects of the price on emissions for the period 2010-2019, to establish a difference between emissions before the introduction of the tax, and after the implementation, for total French emissions, and particularly, for the road transport sector, which we consider to be more sensible to increases in fuel prices.

i. Previous carbon tax attempts

The Ecotax (2000) is the first French tentative to introduce carbon taxation in the national economy, under the influence of the adoption of the Kyoto Protocol in 1997, the first international agreement setting legally binding targets on carbon reductions.

In the aftermath of the Rio Earth Summit, the EU attempted in 1992 to introduce a harmonised tax on fossil fuels, according to the carbon emissions associated with their use, which would have established a minimum tax rate level for each fossil fuel across Member States. However, this initiative was hindered by the opposition of some governments. In 1995, a new shot was given to harmonise taxes on fossil fuels, with more flexible conditions, but it was rejected once again (Padilla and Roca, 2004). These two failed attempts showed that if measures were to be taken to reduce carbon emissions through taxing carbon, they would have to be taken by each Member State independently.

France already had around fifty taxes related, to some extent, to the environment, but the framework lacked coherence and it did not express its wish to protect the environment (Bricq, 1999). In 1999, the government adopted the *Taxe Générale sur les Activités Polluantes* (TGAP), in force from the 1st of January 2000, to make the tax system in France more coherent. However, fearing that current policies would not work to achieve the GHG emissions reduction commitments, authorities aimed to extend the scope of TGAP to the energy sector, naming this extension the Ecotax. It affected intermediate fossil fuel energy (from natural gas and coal, heavy fuel oil, heating oil and liquefied petroleum gas) and electricity consumption.

Two main factors, in the preparation of the tax, set the Ecotax to failure. Firstly, the lack of adequate communication of the aim of the tax. Part of the allocation of the

Ecotax revenues was meant to compensate the diminution of social security contributions due to the newly stablished 35-hour workweek. Therefore, the message sent to the citizens did not correspond to the initial goal of the tax: what was thought to be a measure to protect the environment seemed to be another way to increase tax collection in France (Rocamora, 2017).

Secondly, the wide range of tax exemptions recognised in the bill. Since the process of negotiation of the Ecotax started, the proposal led to many economic actors opposing to the measure. In the end, to make sure the tax would be socially accepted, a threshold of 100 tonnes of oil equivalent (TOE) of energy product per year was set, below which taxpayers were not subject to the Ecotax, which virtually exempted households from the tax. Moreover, while it seemed to leave the tax burden to companies only, due to the social negotiations, many other exemptions were included. The most remarkable, the existence of an abatement coefficient that increased progressively with energy consumption (Rocamora, 2017).

These factors led to social and political opposition, which sent the Ecotax to be examined by the French *Conseil Constitutionnel*. In the *Décision n° 2000-441 DC du 28 décembre 2000*, the *Conseil Constitutionnel* appreciated two incoherencies between the tax structure and the Explanatory Memorandum of the Ecotax, which stated that its objective was to reinforce the fight against GHG emissions, inciting companies to improve the consumption patterns on energy products.

Regarding the abatement coefficients, these "could lead to a company being taxed more heavily than a similar company, even though it would have contributed less to the release of carbon dioxide into the atmosphere" (section 36). Concerning electricity taxation, it remarked that it was planned "even though due to the nature of the sources of electricity production in France, the consumption of electricity contributes very little to the release of carbon dioxide" (section 37). In the end, the *Conseil* considered that the Ecotax vulnerated the principle of equity in taxation and that it had to be considered against the Constitution.

A new attempt to create a carbon tax took place with the Carbon Contribution (2009), the result of a pledge during the presidential campaign of Nicolas Sarkozy. The adoption of a carbon tax was contemplated within the environmental agenda created with the *Grenelle de l'Environnement*, an open multi-party discussion that brought together representatives of the local and national government, and employers, labour unions and non-governmental organisations (NGO), with the goal of unifying a position on the environmental field (Boy, 2010).

Along with the campaign pledge, the carbon tax was meant to be the specific tool needed to achieve the domestic (e.g., the Factor 4 objective, a reduction of CO2 emissions by a factor of four by 2050) (Henriet *et al.*, 2014) and international commitments (e.g., the EU target on the Kyoto Protocol and the target agreed on the L'Aquila summit, within the G8 framework) on reduction targets.

The project of 2009 aimed at amending the mistakes of the carbon tax of 2000. To achieve unanimous consensus among stakeholders, a series of expert reports were presented. They concluded the need of the carbon tax to spur change in the behaviour of economic actors (Landau, 2007). Moreover, that the price should start at around EUR 32 per ton of CO2 and should progressively increase (Quinet, 2009), to ensure social acceptability, and that the major principles for the effective price signal were predictability (spanning over the long term), progressiveness (increase over time), additionality (differentiating from other existent taxes) and environmentality (designing the tax according to its objective of reducing CO2 emissions) (Rocard, 2009).

Despite the efforts in the preparation of this second carbon tax, the government failed at communicating the benefits of the carbon tax, the public were worried about whether the tax would be neutral because compensation mechanisms for households and companies were not clear, and the carbon tax was seen as another fiscal burden, which was not welcomely received by a country affected by an economic crisis.

The carbon tax was finally adopted in the *Loi de Finances pour 2010* but with a price of EUR 17 per ton. It did not include a pluriannual plan for its increase and it only targeted the consumption of fossil fuels, leaving electricity out. The problem with this second attempt was again the inclusion of numerous exemptions.

On the one hand, industrial installations that were already under the EU-ETS regime, and those awaiting their inclusion in the following phases, enjoyed of total exemptions. On the other hand, non-industrial sectors (e.g., agriculture, fisheries, public transport) that, according to the government, risked losing competitivity or were deemed to already making up for their GHG emissions under other policies, were benefited with exemptions and reduced targets (Rocamora, 2017). The real impact of the carbon tax was to increase the prices of fuel and gas for housing and office heating, and for transportation.

Opposition led to bringing the tax before the *Conseil Constitutionnel* again. In the *Décision n° 2009-599 DC du 29 décembre 2009*, the Conseil stated again that even if "the objective of the carbon contribution [was] to "put in place instruments allowing a significant reduction in greenhouse gas emissions"", the exemption regime lacked coherence. It remarked that while some companies were exempted from paying because of submission to the EU-ETS, "the paid quota regime [would] only come into force in 2013 and [would] do so gradually until 2027", the allowances being in that moment handed in for free. Therefore, the tax only levied fossil fuels and other heating products, which entailed only a fraction of the carbon emissions.

The Conseil considered that "by their importance, the total exemption regimes […] [were] contrary to the objective of combating global warming and create[d] a marked breach of equality before public charges", therefore, it appreciated the unconstitutionality of the contribution, due to the inefficiency of its environmental incentive. As an example of this inequality, the carbon contribution would have taxed more heavily road transport than aviation, a sector that was excluded from the tax, whose inclusion in the EU-ETS was not envisaged at least before 2013, and which is a higher CO2 emitter in terms of tonne/transported kms or passengers/km transported; therefore, the price signal to reduce emissions would have been inexistant (Sainteny, 2010).

After this, a new carbon tax project was initiated in 2010, but it was finally abandoned, and the climate agenda was finally being put aside, fearing to run again against the opposition from households and to undermine French companies' competitiveness (Callonnec *et al.*, 2012).

These are the short-lived stories of the first two attempts to introduce a carbon tax in France, describing in which context they were proposed, their goals, the structure of the taxes and the reasons why they did not succeed.

ii. The Climate-Energy Contribution (2014 – at present)

Climate policies were put on the table again with the rise of the Socialist Party in the presidential elections of May 2012. The first idea was to create the Climate-Energy Contribution (CCE) as a new tax that would not only tax carbon-emitting actions, but also energy consumption, excluding renewable energies. In the end, the government proposed a CEE that would not be a new tax, but an increase in the already existent *Taxe intérieure de consommation sur les produits énergétiques* (TICPE), a tax on the consumption of energy products.

During the development of the project, the Ministry had the support of a Committee for Ecological Taxation that, in July 2013, published a report in which it insisted on the importance of adopting a wide tax coverage, with as little exemptions as possible, and balanced by an appropriate compensation system, for households and companies.

With the backing of the report, fourteen years after the first attempt to introduce carbon pricing in France, the CCE was finally included in the *Loi de Finances pour 2014*. As suggested by the report, it was a carbon component in the existing energy taxes, the TICPE being the most important, but also in the *Taxe Intérieure de Consommation sur le Gaz Naturel* (TICGN) and the *Taxe intérieure de consommation sur le charbon* (TICC) (Chiroleu-Assouline, 2015). Furthermore, in order to allow exemptions while avoiding the infringement of the principle of tax equality, the CEE was not defined as an environmental tax (Rogissart *et al*., 2018).

The tax established a carbon price of EUR 7/tCO2 in 2014, EUR 14.5/tCO2 in 2015 and EUR 22/tCO2 in 2016, as the Ministry manifested (2014). This carbon component was not explicit for energy buyers; instead, it was calculated by the customs service, therefore, through upstream taxation (Gloriant, 2018).

In August 2015, the Parliament adopted the *Loi n° 2015-992 du 17 août 2015 relative à la transition énergétique pour la croissance verte (LTECV)*. This act included many important environmental targets to be achieved by France in the following years and decades. Among others, a reduction of 40% in GHG emissions by 2030, and 75% by 2050, compared to 1990 levels; a reduction on the consumption of energy, by 20% in 2030, and 50% in 2050; increasing the share of renewable energies in France's energy mix, up to a 32% in 2030; or reducing the one of nuclear, from 75% to 50%, in 2025.

Aside from these, the LTECV also established new targets for the price of carbon in the CCE, of EUR 56/tCO2 in 2020, and EUR 100/tCO2 in 2030. Furthermore, the same act was amended in December of the same year, driven by the effects of the 2015 UN Climate Change Conference in Paris, to set the prices for the period 2017-2019: EUR 30.50/tCO2 in 2017, EUR 39/tCO2 in 2018 and EUR 47.50/tCO2 in 2019. Hence, the inclusion of a carbon tax price for 2030 is important, not only in terms of a long-term perspective of the tax, but also because the carbon tax is linked with the broader climate change mitigation targets of the country. However, the effective increase in the tax required each Finance Act to annually adopt the increase.

Table 1

Initially planned progression of the carbon price in the CEE after 2014 (in euros/tCO2)

	2014	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2030**
Carbon price	7	14,5	22	30,5	39	47,5	56	100
Augmentation (compared to the previous year)	+7	+7,5	+7,5	+8,5	+8,5	+8,5	+8,5	-

Note. Between 2014 and 2015, the prices for the carbon tax were initially planned to increase following the trend on the table. Increases for the period 2021-2030 were left for future approval. Source: Luche (2017).

The first years of the CCE went by without major incidents or great opposition, unlike the two previous attempts. The increase of the tax until 2017, which essentially quadrupled the carbon price, from EUR 7 to EUR 30, went unnoticed, or at least, no public opposition raised against it.

An important factor that contributed to public acceptance was a concomitant steady decline of the oil price over the last few years, as the price increase in fuels was deemed bearable by both households and companies and it came almost unnoticed (Schubert, 2019). Additionally, the TICPE for oil was also partially offset and companies covered by the EU-ETS were entitled to reimbursement of the tax. Consequently, the price signal goal of the carbon tax was clouded by the sharp fall in overall prices of raw materials (Gloriant, 2018).

In 2018, the combination of a series of events, namely the announcement in November of an acceleration in the increase of the carbon tax, tax adjustments adopted to make gasoline and diesel prices converge, and an important increase of the oil price since 2016, led to public mobilisations, commonly known as the "Yellow Vests protests", to protest the increase in the carbon price. For households living in non-metropolitan areas, which generally drove diesel cars for personal or professional activities, the increase was deemed unbearable (Criqui *et al*., 2019).

Table 2

Fuel price evolution between September 2017 and September 2018 in France

		September 2017	**September 2018**	**Variation**	
		Euros/litre	*Euros/litre*	*Cents/litre*	*%*
Super unleaded 95	**Producer price**	0,59	0,74	14,5	24,4
	Energy taxes	0,78	0,82	3,9	4,9
	Consumer price	1,37	1,56	18,4	13,4
Diesel	**Producer price**	0,58	0,77	18,2	31,2
	Energy taxes	0,64	0,71	7,6	11,9
	Consumer price	1,22	1,48	25,8	21,1

Note. In just a year, the cumulative effects of different factors that altered the final consumer price for oil led to important increases in fuel prices. Source: Schubert (2019).

In fact, for the year 2018, it had already experienced an increase higher that the initially planned, as it was firstly expected to be of EUR 39 per tonne, but it turned out to be EUR 44.6/tCO_2, after the *Loi de Finances pour 2018* anticipated this. Following the Yellow Vest protests, the proposed increase for the year 2019 of EUR 55 per tonne, together with the tax adjustment for the petrol and diesel gap, were abandoned, and the tax was frozen to EUR 44.6 per tonne, a price that has not yet been increased (Bureau *et al.*, 2019).

iii. Analysis of the effects of the CEE in France

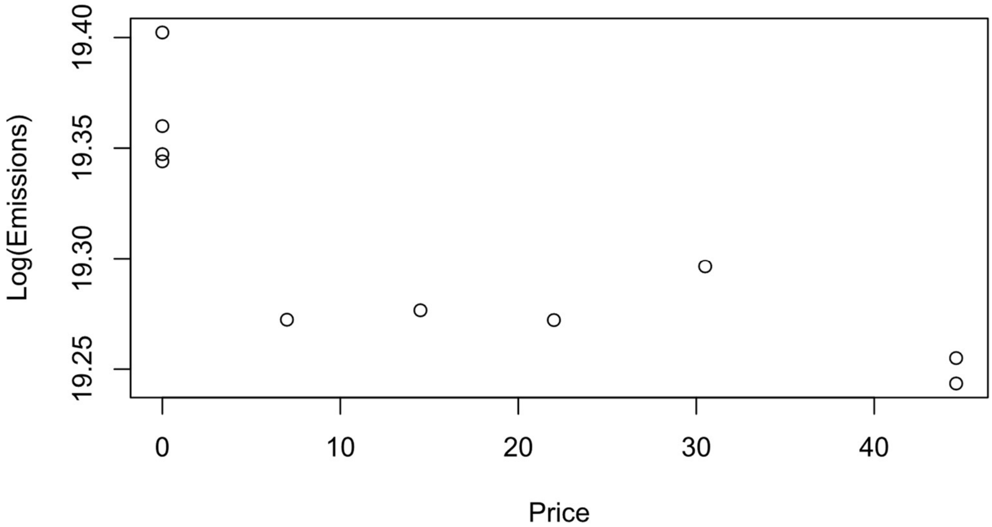
The CEE has had, so far, a short life, and a troubled one too. Some experts consider that to avoid the failure on the implementation of a carbon tax, four dimensions must be fulfilled: ecological efficacity, social justice, legal compliance, and politic acceptability (Berry and Laurent, 2019). In this section, we will focus on the ecological efficacity dimension, that it, the efficacity on reducing emissions.

Unlike the case of the EU-ETS, studying the effects of the carbon tax in France's CO_2 emissions since its implementation turns out to be slightly more difficult. To carry out our research, we will assess what the trend on emissions has been since the implementation of the tax in 2014, and we will attempt to perform a regression analysis, for total emissions so far, but also for emissions in the road transport sector, expected to be slightly more sensible to the introduction of a carbon tax, due to the effects of the tax on the fuel price. Therefore, we will assess which has been the relationship between the price and the emissions, and the carbon price will be linked to emissions, in a slightly similar way compared to earlier.

The data used for this assessment is that of emissions for the period 2010 – 2019, provided by the INSEE, considering the introduction of the first carbon price in the year 2014. To start with the analysis, we will begin with the construction of a plot for total emissions (Figure 16) and road transport emissions (Figure 17). Just like for the EU-ETS, in the variable Y, referring to emissions, we will apply a log transformation to make our data distribution less skewed.

Figure 16

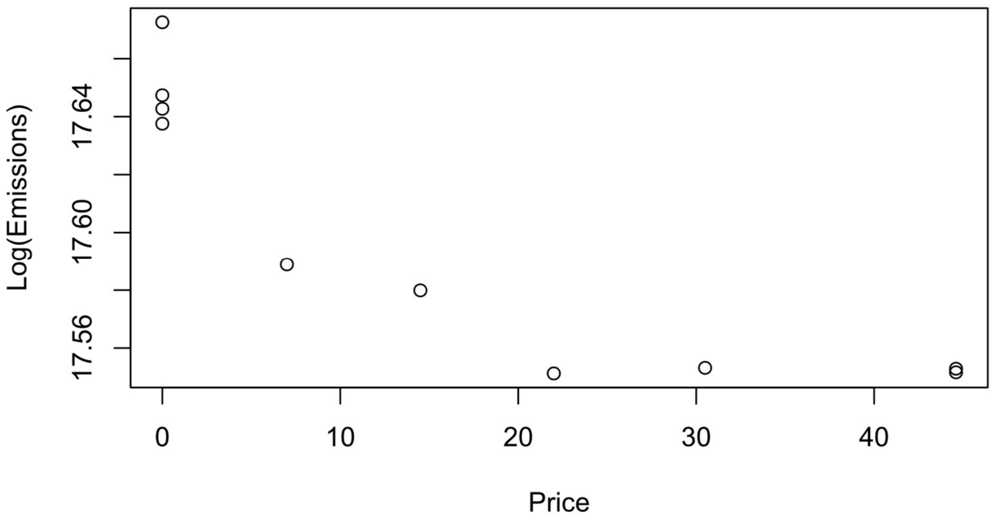
Scatter plot for the carbon tax price and the total emissions for the French economy (log transformation applied)



Note. From the data on emissions on the INSEE and the carbon price established for each year in the *Loi de Finances*.

Figure 17

Scatter plot for the carbon tax price and the emissions of the French road transport sector (log transformation applied)



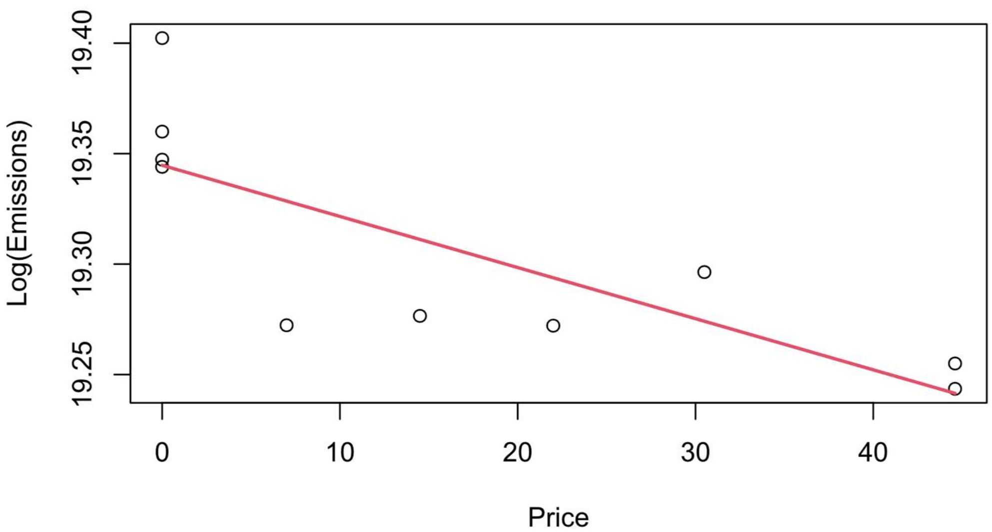
Note. From the data on emissions on the INSEE and the carbon price established for each year in the *Loi de Finances*.

A priori, from the scatter plots, we perceive, more easily than in the case of the EU-ETS, that a higher carbon price (or carbon component, to be more precise) is linked to lower emissions. For our statistical models, our null hypothesis is there is no correlation between emissions and carbon price, and the alternative hypothesis is there is correlation. If, through our models, we rejected the null hypothesis, it would imply there is a relationship between French emissions and the carbon tax.

For total emissions, the model specification was as follows: log(Total emissions) ~ b0 + b1 * Price, therefore, using only the linear term of price, expressed in EUR. The results from the regression show there were significant effects of the carbon component price on carbon emissions for the total of the French economy for a significance level of 5% (b1 = - 0.0023144, t(8) = -3.759, p = 0.00555). It shows that there is an inverse correlation between the French carbon price and the tonnes of CO2 emitted by the total of the economy (Figure 18). Therefore, the interpretation is that for every 1-unit increase in the *Price* variable, the *log(Emissions)* variable decreases by the beta coefficient value, that is, 0.0023144.

Figure 18

Regression line between the carbon tax price and the total emissions for the French economy (log transformation applied)

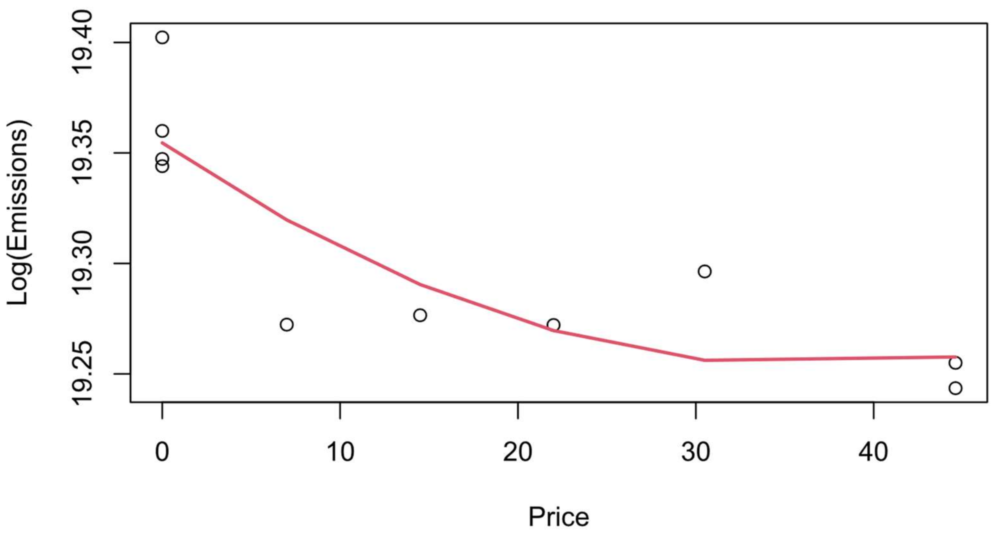


The adjusted R-squared for our model is 0.5933. As a reminder, the R-squared, also known as coefficient of determination, shows how well the data points of our sample fit a line or curve. The adjusted R-squared also indicates this adequacy, but also adjusts for the number of terms of our model. That is, if we add more variables considered not useful, the adjusted R-squared decreases. This precision is made because the data points in our scatter plot seem to follow an exponential path rather than linear, so we might consider adding a quadratic term for the variable *Price*, to check if such specification would provide a better explanation for our model.

The second model specification was as follows: log(Total emissions) ~ b0 + b1 * Price + b2 * Price^2. The results from this non-linear regression show that there were significant effects of the carbon component price on carbon emissions for the total of the French economy for a significance level of 5% (b1 = - 5.504e-03, t(7) = -2.584, p = 0.0363), but the non-significance of our quadratic term (b2 = 7.470e-05, t(7) = 1.554, p = 0.1642). However, the adjusted R-squared increases, with a value of 0.6544, thus this model fits our data better than the one with the linear regression. It shows that there is an inverse correlation between the French tax and the tonnes of carbon emitted by the country (Figure 19).

Figure 19

Non-linear regression between the carbon tax price and the total emissions for the French economy (log transformation applied)



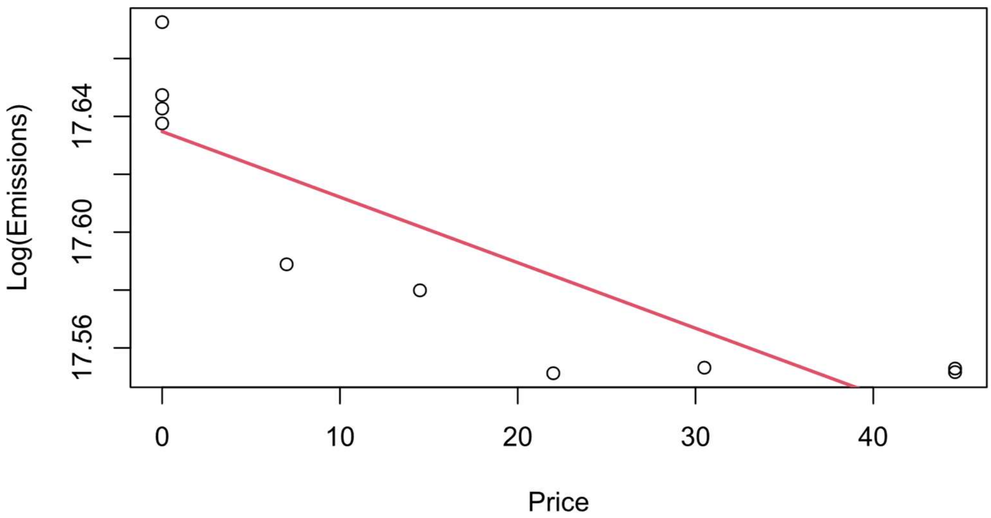
Note. This model fits our data slightly better than the previous linear regression, corroborated by the adjusted R-squared.

The interpretation of this second model is that, for the linear term, for every 1-unit increase in the *Price* variable, the *log(Total emissions)* variable is expected to decrease by 5.504e-03. The quadratic term, as a kind of interaction, tells us about the expected direction and change of our slope as the value of *Price* changes. Since 7.470e-05 is positive, the slope is expected to be more positive as *Price* increases, and, for each 1-unit increase in the *Price* variable, the slope increases by 2 times the quadratic term (that is, the derivative of $Price^2$), 7.470e-05 * 2.

For emissions from the road transport sector, the model specification was as follows: log(Road transport emissions) ~ b0 + b1 * Price, again using only the linear term of price, expressed in EUR. The results from the regression show there were significant effects of the carbon component price on carbon emissions for the road transport sector for a significance level of 5% (b1 = -0.0022650, t(8) = -4.941, p = 0.00113). It shows that, also for the road transport sector emissions, there is an inverse correlation between the French carbon tax price and the emissions (Figure 20). The interpretation is that for every 1-unit increase in the *Price* variable, the *log(Road transport emissions)* variable decreases by 0.0022650.

Figure 20

Regression line between the carbon tax price and the emissions from the French road transport sector (log transformation applied)

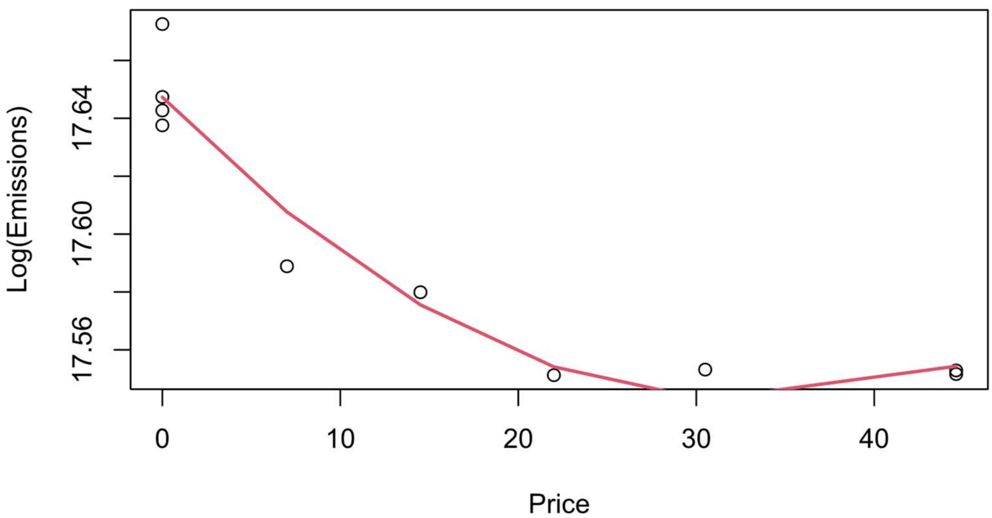


Just like it was done with the linear regression model, if the adjusted R-squared is checked for this model, the value is 0.7224, which means that 72.24% of our data fits our model. But since the path of our data is rather not linear, and the introduction of a quadratic term in the case of total emissions was useful to draw a better model, it is also recommended to do the same here.

The second model specification was as follows: log(Road transport emissions) ~ b0 + b1 * Price + b2 * Price^2. The results from this non-linear regression show that there were significant effects of the carbon component price on carbon emissions for the total of the French economy for a significance level of 5% (b1 = -6.329e-03, t(7) = -6.895, p = 0.000232), and also the significance of our quadratic term (b2 = 9.517e-05, t(7) = 4.593, p = 0.002504). Moreover, the adjusted R-squared increases, with a value of 0.921, versus the previous 0.7224. It shows again that there is an inverse correlation between the French carbon tax and the tonnes of carbon emitted by the road transport sector in France (Figure 21).

Figure 21

Non-linear regression between the carbon tax price and the emissions from the French road transport sector (log transformation applied)



Note. This model fits our data slightly better again (also corroborated by the adjusted R-squared).

The interpretation of this second model is that, for the linear term, for every 1-unit increase in the *Price* variable, the *log(Road transport emissions)* variable is expected to decrease by 6.329e-03. For the quadratic term, since 9.517e-05 is positive, the slope is expected to be more positive as *Price* increases, and, for each 1-unit increase in the *Price* variable, the slope increases by 2 times the quadratic term, that is, 9.517e-05 * 2.

For both for the total emissions and the emissions from the road transport sector, this quadratic term leads us to a positive slope after reaching a certain carbon tax price. This is due to the quadratic term adjusting our regression by a parabolic function. It is important to remark, before drawing conclusions from this effect, that this increase in emissions lacks an empirical basis and that they are just an artifact of our econometric models.

In any case, our conclusions for the analysis of the French carbon tax are that results have shown there is a significant relationship between the French carbon tax price and the emissions generated in France for the time it has been in force. Especially for the road transport sector, our models were capable of explaining in great measure the evolution of the emissions generated.

However, our data worked with carbon tax prices as high as EUR 44.6, after the Yellow Vests protests led to its freeze, despite the tax expected to rise to EUR 100 by the end of this decade. Even though the significant relationship between both variables has been stated by our models, the sudden freeze in the price of carbon limited our study findings, results that were already going to be limited by the short time frame considered for our study of the carbon tax.

Again, like in the case of the EU-ETS, the results should be carefully considered and unquestionable statements regarding the French carbon tax and emissions should be avoided. Our models might fit our data, despite the carbon tax not being the only and most powerful driver on the evolution of emissions, but our models, regardless of their oversimplification, strictly show there is a significant relationship between the evolution of the carbon tax price in France and emissions, for the period 2010-2019. This is an analysis from the past, but future works will be advised on continuing studying the future trends.

The previous experiences with the carbon tax show that failing to communicate the tax properly leads to people believing that individual costs to adjust to the tax are immediate and high, while the benefits are late and uncertain. One of the main issues in the communication scope is the loudness of the anti-tax arguments, which are generally not true, but are effective enough to reach more people (Hourcade, 2015). For the future increase of the carbon price in France's CEE, which will undoubtedly be needed, this communication must be directed to address the perceived inadequacy between carbon taxation and environmental protection.

Experts have figured out that the French population is not against the climate polices but the carbon tax. French people are concerned about the environment, but their beliefs about carbon taxation are biased by those anti-tax arguments, making the reintroduction of increases in the tax difficult in the short term (Douenne and Fabre, 2019). Therefore, future information campaigns should not only be addressed to improve citizen knowledge on climate change, but to clearly explain the role of climate policies, such as carbon taxation.

It is important to reinforce the idea that an effective climate policy would require, not only a carbon pricing mechanism, but also instruments to ensure the revenue neutrality of the tax, and the combination with regulations and subsidies to incentivise the conversion and the innovation in the renewable fields, and green investments (Bureau *et al.*, 2019). Since market imperfections exist and there are always concerns on the distributive effects of the tax, focusing the mitigation mechanisms of a country on a single price signal provided by the carbon tax is less recommendable than combining different types of climate policies (Douenne and Fabre, 2019). This could lead to wider public acceptance of the French carbon tax, and the possibility of reaching the EUR 100 target for 2030, by all odds, needed to fight climate change.

V. Conclusions

First. Fighting climate change is probably the most important challenge of this century. Despite it not seeming strictly urgent, compared to other issues affecting the international community nowadays, the irreversible threats we face if it is not managed before it is too late, should push us to react with effective policies immediately. However, this is not the case in current international relations, where soft law agreements and heterogeneous and unequal, rarely binding commitments prevail. Efforts must be enhanced so that homogenous legally-binding instruments are signed by all Nations to fight climate change.

Second. Since climate change is global, its effects will take place all over the planet. Nonetheless, an important remark of climate change is that it will not affect each country insomuch as the country contributed with its carbon emissions. Coastal areas will be affected by SLR, agriculture-based countries by the increase in temperatures, all of them independently to their contribution to climate change. Therefore, a strictly economic appraisal of the consequences of it, such as the one proposed by Nordhaus, is useful, but questionable, to the extent it values everything arbitrarily in monetary units. Principles of International Law, namely of solidarity, should also be taken into account, before assessing in terms of profitability the losses of disadvantaged communities.

Third. Making the polluters pay for the carbon emissions they generate complies, not only with Environmental Law principles, such as the PPP, but also answers to an economic logic, as emissions are negative externalities that generate costs (if not in the immediate future, eventually, when public investments to deal with the effects of climate change will have to be made), unborn by the emitters. For that reason, carbon pricing is essential to allow the products in an economy to give a price signal on the carbon-intensity of their production processes, thus, making every single economic agent capable of making environmentally-sensible choices in their daily decisions on consumption, among others.

Fourth. While cap-and-trade offers a favourable carbon pricing mechanism for companies, as they can gradually adapt their production processes to reduce emissions, cap-and-trade is not necessarily superior to a carbon tax, since the latest can also include households, that constitute a great source of emissions, and implementation can be more straightforward. However, public support for taxes is low. Despite the evidence that they do indeed reduce carbon emissions, people tend to consider them environmentally inefficient and just as another tax burden with no significant effects on climate change mitigation. This might be one of the most complicated challenges in the implementation of a carbon tax as a mitigation policy.

Fifth. The case of France illustrates on the difficulties that any other Member State might face to implement carbon taxation within its borders, not only due to its political difficulty, but also due to the inferences between the tax and the EU-ETS. It shows how it is possible to go from failure to success, still failing afterwards, if the tax is not properly designed to combine the different dimensions of carbon taxation. But since carbon pricing is essential for the national decarbonisation strategies, strong steps should be made to guarantee the success, as inefficient designs risk not allowing the desired effect on the reduction of emissions and might jeopardise the achievement of internationally-agreed pledges.

Sixth. As regards the EU-ETS, we cannot conclude that this market carbon price causes emissions to decrease, but we have found there is a significant relationship, statistically talking, between these, at least for some of the highest emitting French companies subject to it. Yet, the reduction on the emissions could be due to other reasons, like the adoption of CSR strategies or other innovations for which a reduction on emissions would only come as an externality. This should not be regarded as a reason to abandon the EU-ETS, but rather to reflect on the fact that prices in the EU-ETS since its implementation might not been sufficiently high, nor stable, to signal companies on the need to reduce emissions.

Seventh. Total emissions for France and for the road transport sector and the carbon tax evolution has been econometrically assessed and it has also been found that there is a significant relationship between these. The price signal of the tax is this case is clearer than in the EU-ETS, since the price was increased since its introduction in 2014 until 2018, when it was frozen due to public opposition. To continue assessing the effects of carbon taxation in France, future works are advised to work with wider time frames, but especially after experiencing new price increases in the tax. Such data would reinforce the beliefs regarding the effectivity of carbon taxation to fight climate change if those higher prices triggered further emission reductions.

Eight. As long as the two studied carbon pricing mechanisms coexist among Member States, a better balance is needed. Once Phase 4 of the EU-ETS kicks off and companies stop receiving free allowances, some kind of exceptions regarding the national taxes will have to be designed so that companies subject to the EU-ETS are not taxed twice. In order to establish tax exceptions accepted by the public opinion, it will be important to transparently communicate these exceptions. However, these exemptions will only be fair as long as the companies do not enjoy of extra benefits in the European ETS, such as free allowances or significantly lower carbon prices. The only effective, and also fair, mechanism to protect domestic industries will be the inclusion of a carbon border adjustment mechanism.

Ninth. The importance of communication in carbon pricing should be understood in a wide sense. The resistance against carbon taxes by citizens mainly comes from biased opinions about the efficacy of these to mitigate the effects of climate change. It is a subject that has been widely studied by economists during the last decades, and it has been proven that carbon pricing mechanisms work for this purpose of reducing carbon emissions. Like in the case of France, the public is already generally concerned about climate change and environmental issues. Therefore, communication by public institutions must be directed to address the disinformation regarding these mechanisms, rather than the environmental awareness.

Tenth. Fighting climate change might be questioned by current generations, for which duties before the planet exist, despite not being strictly responsible of the experienced changes, nor probably enjoying the future benefits of slowed climate change. Nevertheless, taking action on the planet is a matter of exemplarity across nations, and across generations. It might seem unfair to act when other nations are not engaging in the protection of the environment, but not us taking action would neither be fair for future generations. We cannot let ourselves to make them live in a world we altered to the extent it reported economic benefits, just because we put a price on *goods* such as the “having polar bears in the wild” or “not making most of the Pacific islands disappear”, and mitigation was not economically desirable.

VI. Annotated bibliography

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VII. Annotated bibliography

A. RStudio outcome from the EU-ETS analysis.

```
Linear mixed-effects model fit by REML
  Data: DFETS
       AIC      BIC    logLik
  187.4978 197.9977 -89.7489

Random effects:
 Formula: ~1 | variable
        (Intercept)  Residual
StdDev:   0.6897083 0.4879096

Fixed effects:  log(value) ~ Settle
                Value  Std.Error DF  t-value p-value
(Intercept) 15.454107 0.26140385 95 59.11966  0.0000
Settle      -0.013322 0.00623315 95 -2.13721  0.0351
 Correlation:
       (Intr)
Settle -0.31

Standardized Within-Group Residuals:
        Min          Q1         Med          Q3         Max
-6.75956244 -0.28711517 -0.02979089  0.32500263  2.19799535

Number of Observations: 104
Number of Groups: 8
```

Value = Emissions in million tonnes

Settle = EU-ETS price in euros

B. RStudio outcomes from the French carbon tax analysis.

For total emissions:

```
Call:
lm(formula = log(Emissions) ~ Price, data = doming2)

Residuals:
      Min        1Q    Median        3Q       Max
-0.056208 -0.016427  0.002307  0.014815  0.057574

Coefficients:
              Estimate Std. Error  t value Pr(>|t|)
(Intercept) 19.3447171  0.0146373 1321.608  < 2e-16 ***
Price       -0.0023144  0.0006157   -3.759  0.00555 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.03366 on 8 degrees of freedom
Multiple R-squared:  0.6385,    Adjusted R-squared:  0.5933
F-statistic: 14.13 on 1 and 8 DF,  p-value: 0.005552
```

For log(total emissions):

```
Call:
lm(formula = log(Emissions) ~ Price + I(Price^2), data = doming2)

Residuals:
      Min        1Q    Median        3Q       Max 
-0.047378 -0.013062 -0.004963  0.004687  0.047735 

Coefficients:
              Estimate Std. Error  t value Pr(>|t|)    
(Intercept)  1.935e+01  1.490e-02 1298.533   <2e-16 ***
Price       -5.504e-03  2.130e-03   -2.584   0.0363 *  
I(Price^2)   7.470e-05  4.808e-05    1.554   0.1642    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.03103 on 7 degrees of freedom
Multiple R-squared:  0.7312,    Adjusted R-squared:  0.6544 
F-statistic: 9.521 on 2 and 7 DF,  p-value: 0.01007
```

For road transport emissions:

```
Call:
lm(formula = log(Transp) ~ Price, data = doming2)

Residuals:
      Min        1Q    Median        3Q       Max 
-0.033677 -0.019638  0.005381  0.016577  0.037809 

Coefficients:
              Estimate Std. Error  t value Pr(>|t|)    
(Intercept) 17.6347622  0.0108970 1618.315  < 2e-16 ***
Price       -0.0022650  0.0004584   -4.941  0.00113 ** 
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.02506 on 8 degrees of freedom
Multiple R-squared:  0.7532,    Adjusted R-squared:  0.7224 
F-statistic: 24.42 on 1 and 8 DF,  p-value: 0.001133
```

For log(road transport emissions):

```
Call:
lm(formula = log(Transp) ~ Price + I(Price^2), data = doming2)

Residuals:
      Min        1Q    Median        3Q       Max 
-0.018775 -0.004153 -0.002077  0.003295  0.025275 

Coefficients:
              Estimate Std. Error  t value Pr(>|t|)    
(Intercept)  1.765e+01  6.423e-03 2747.624  < 2e-16 ***
Price       -6.329e-03  9.179e-04   -6.895 0.000232 ***
I(Price^2)   9.517e-05  2.072e-05    4.593 0.002504 ** 
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.01337 on 7 degrees of freedom
Multiple R-squared:  0.9385,    Adjusted R-squared:  0.921 
F-statistic: 53.43 on 2 and 7 DF,  p-value: 5.761e-05
```