ΟΙΚΟΝΟΜΙΚΟ ΠΑΝΕΠΙΣΤΗΜΙΟ ΑΘΗΝΩΝ

ATHENS UNIVERSITY OF ECONOMICS AND BUSINESS

UNDERGRADUATE THESIS

«Environmental Economics:

European Union Emissions Trading System

& Carbon Tax: a review of the two methods of Carbon Pricing»

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ABSTRACT

This thesis analyzes the implementation of the two carbon pricing measures: the Carbon Tax and the Greenhouse Gas Emissions Trading System, within the European Union. Reducing greenhouse gas emissions is one of the main goals of the World Community. That is why the study and implementation of the two measures has been in the spotlight in the recent years. Our aim is to study these measures, how much they have changed over the last few years, and what factors have contributed to this change. The performance of the Carbon Tax and the European Union Emissions Trading System can guide political leaders to implement and form these measures. Many describe the carbon pricing measures as a failure, while others describe them as two of the most important environmental policies. The only sure thing is that there has been a reduction in carbon dioxide emissions and other harmful gases -even a small one - something that is remarkable if we consider the short time of implementation of the two measures. In the coming years, we hope to reduce the level of global emissions and turn to the use of renewable energy sources.

KEYWORDS

Global Climate Change, Carbon Pricing, Carbon Taxes, Cap & Trade System, European Union Emissions Trading System, Renewable Energy Sources

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Chapter 1: Introduction

The Paris Agreement, in 2015, was a powerful incentive for governments to review their current environmental policies to achieve decarbonization. The basic policy for such an endeavor is carbon pricing.

Carbon pricing consists of three measures: the greenhouse gas emission trading system, the carbon tax or a hybrid mechanism, which combines the above two measures.

In the emission trading system, the government of each country or, in the case of the European Union, the institution, sets a specific cap for greenhouse gas emissions (which covers and other gases other than carbon dioxide) in various sectors and distributes allowances to pollutants, which should be equal to the amount of their emissions. Whereas, in case of non-compliance, a fine is imposed.

A carbon tax, on the other hand, depends on each government, which sets a tax rate, as well as the sectors covered by the tax.

This thesis focuses on the European Union Emissions Trading System, the implementation of the Carbon Tax in European countries and how environmental taxes are a deterrent to the use of fossil fuels - which significantly increase emissions - by companies.

The thesis is organized as follows:

- The first section presents basic information about climate change, the greenhouse effect, the three main gases (carbon dioxide, methane, nitric oxide) and global warming.
- The second section introduces the concept of the European Union Emissions Trading System, the historical background before its creation, its basic characteristics, the four phases of the program, its changes, the emission levels for the Member States in each phase and an evaluation of the program.
- The third section gives the definition of the carbon tax and the way of its implemented. It also presents the European countries that have implemented the measure, as well as the tax rate for each country. In addition, there are brief case studies on the application of the tax in five European countries (Norway, Sweden, Denmark, Finland, United Kingdom). Also, there is an economic analysis about the social efficiency of a carbon tax. Finally, a comparison of the two carbon pricing measures is made.
- The forth -and last- section consists of a panel data analysis of 27 EU member states for 9 years, from 2009 to 2018. The dependent variable is the rate of renewable energy sources

usage and the dependent variables are: pollution taxes, total environmental taxes, energy taxes, transportation taxes and total environmental protection expenditures.

Chapter 2: Climate Change

If we ask someone what the definition of "Climate Change" is, the answer will probably be the increase in the average temperature of the Earth's surface. Although, climate change is not just the change in temperature, but also the result of interconnected changes.

Specifically, the term "Climate Change", according to the Intergovernmental Panel on Climate Change (IPCC), refers to any change in climate over the years, due to either natural or anthropogenic causes. (IPCC, 2016)

In the past, climate change was mainly due to natural factors, such as volcanic eruptions, changes in the Earth's orbit, solar radiation etc. However, in recent years, the rapid increase in greenhouse gas emissions has brought in the spotlight the Greenhouse Effect, which is the main reason for climate change.

2.1 Greenhouse Effect

The Greenhouse Effect is a natural phenomenon that increases the temperature at the Earth's surface. The reason for the existence of the Earth as we know it today is mainly due to the greenhouse effect, which keeps the Earth's temperature at 15°C. If nature had not predicted this effect, the Earth's temperature would be -18°C, which would make it uninhabitable.

More specifically, solar radiation – corresponding to short wavelengths – passes through the atmosphere. The 30% of incoming radiation is reflected back into space, while the remaining 70% gets absorbed by the atmosphere (30%), clouds (5%) and mainly by the Earth's surface and the oceans (51%), thus increasing the Earth's temperature. Then, a portion of the thermal radiation (up to 90%) – which corresponds to long wavelengths, in comparison to solar radiation – is emitted back into space, as infrared radiation. This radiation absorbs the gases in the atmosphere, known as greenhouse gases, thereby heating the Earth's surface even further.

The existence of these gases isn't harmful to the planet. However, the problem is caused by human intervention that increases the concentration of greenhouse gases and consequently the temperature of the planet.

2.2 Greenhouse Gases

As mentioned above, greenhouse gases are the gases of the atmosphere – whether natural or anthropogenic – that absorb part of the radiation and emit it back to Earth's surface.

The main greenhouse gases are:

- Water Vapor (H_2O)
- Carbon Dioxide (CO_2)
- Methane (CH_4)
- Nitrogen Oxide (N_2O)
- Ozone (O_3)
- Chlorofluorocarbons (CFC's)

From the above, the naturally occurring greenhouse gases are water vapor, carbon dioxide, methane, nitrous oxide and ozone. Excluding water vapor, the remaining gases increase significantly from human activities. There are also gases that do not come from Earth's natural processes, such as chlorofluorocarbons.

Each greenhouse gas has different chemical properties and can be removed from the atmosphere with different processes. Carbon Dioxide, for example, is absorbed by plants, soil, and the ocean. Whereas gases from human activity are only destroyed by sunlight at the highest part of the atmosphere.

Some of the areas of activity of people, that increase greenhouse gas emissions, are:

- Energy
- Industry
- Agriculture
- Transport etc.

The harmful activity of humans, which led to the rapid increase in greenhouse gases, becomes visible during the Industrial Revolution. During the period 1750-1998 we observe an increase in carbon dioxide by 40%, methane by 150% and nitrous oxide by 20%. Whereas, in the 1920's, "synthetic" chlorofluorocarbons were added to the equation.

In recent years, greenhouse gas emissions have continued to rise sharply – although there has been a slight decline, as in 2014 and 2016. Specifically, in 2017 carbon dioxide emissions increased by 1.6%, while in 2018 by 2.7%.

Greenhouse gas concentrations are measured in ppm (parts per million), ppb (parts per billion), ppt (parts per trillion)
E.g. 1ppm means that there is one molecule of that gas in every 1 million air molecules

Below we will analyze some of these gases.

2.2.1 Carbon Dioxide (CO_2)

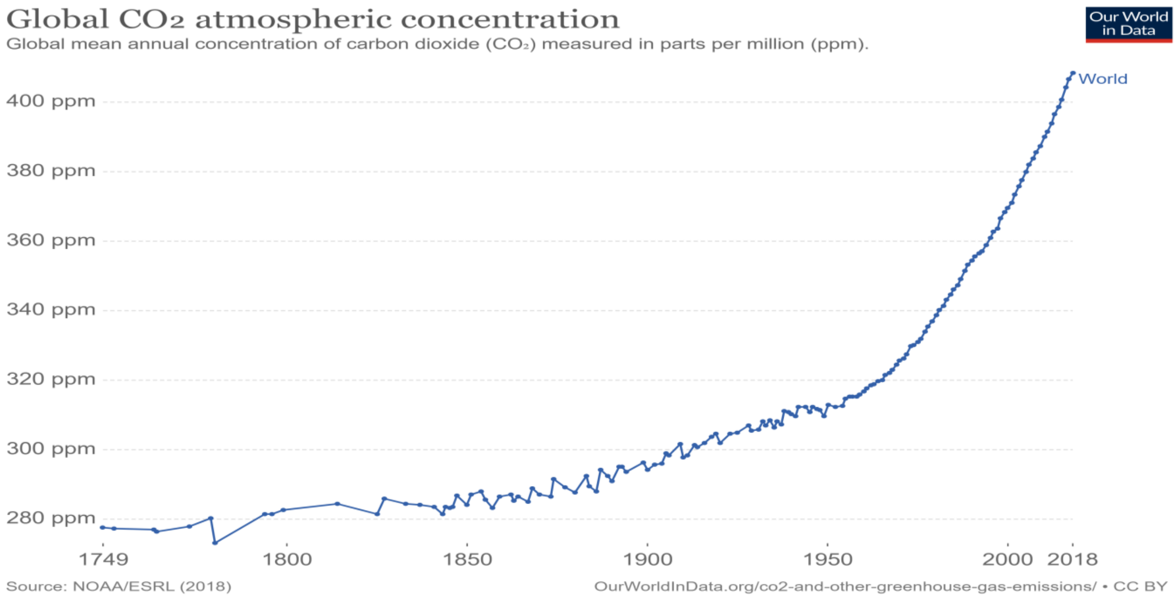


Figure 1 - Global CO2 atmospheric concentration

Carbon dioxide is a "naturally" produced gas emitted by plants and trees through the process of photosynthesis, thus trapping some of the heat. However, the largest share of carbon dioxide emanates from human activity, such as fossil fuel (coal, oil), biomass combustion, industrial activity, transport, etc. According to a 2014 survey, carbon dioxide accounts for 76% of all greenhouse gas emissions from human activity and emissions from combustion of fossil fuels account for 91% of total carbon dioxide emissions from human sources.

It is estimated that before the Industrial Revolution carbon dioxide concentration was 265ppm, 2017 was 405ppm and 2018 was 408ppm. Today carbon dioxide concentration is increasing at about 1.5ppm (0.48%) per year. This means that by 2035 the concentration will reach 420ppm.

Finally, it is worth pointing out that 40% of the carbon dioxide emitted into the atmosphere remains up to 100 years, 20% up to 1,000 years and 10% up to 10,000 years. Therefore, we understand that managing carbon dioxide emissions is of the utmost importance.

In the following chapters we will analyze policies that manage these emissions, with the prime example of carbon tax.

2.2.2 Methane (CH_4)

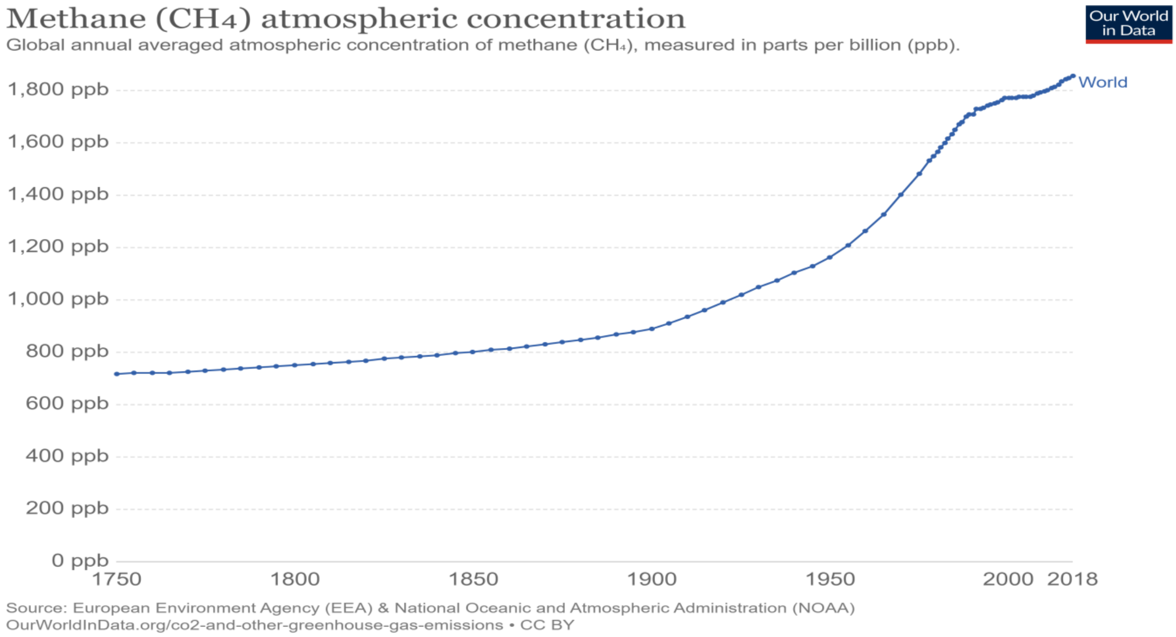


Figure 2 - Global CH4 atmospheric concentration

Methane is the second most concentrated greenhouse gas in the atmosphere, after carbon dioxide. It is the main constituent of natural gas. It is related to the burning of hydrocarbons, to wetlands, to the oceans, to livestock and to agriculture. Methane accounts for 16% of greenhouse gas emissions from human activity.

It is estimated that before the Industrial Revolution methane concentration in the atmosphere reached 700ppb, whereas today its concentration reaches 1800ppb.

It can remain in the atmosphere for a shorter period than carbon dioxide - for about 10 years – it is, however, 25 times more powerful than carbon dioxide, as a greenhouse gas.

2.2.3 Nitrous Oxide (N_2O)

Nitrous oxide is the third in the greenhouse gas concentration after carbon dioxide and methane. It comes from nature and is mainly associated with agriculture and has remained in the atmosphere for about 100 years.

Here too, human intervention is harmful to the environment, since man produces huge amounts of nitrous oxide. It accounts for about 6% of greenhouse gas emissions from human activity. Over the years, man has been increasing his use of nitrous fertilizers, wanting to upgrade the soil and increase his production. So, the nitrous transmission into the soil increases drastically.

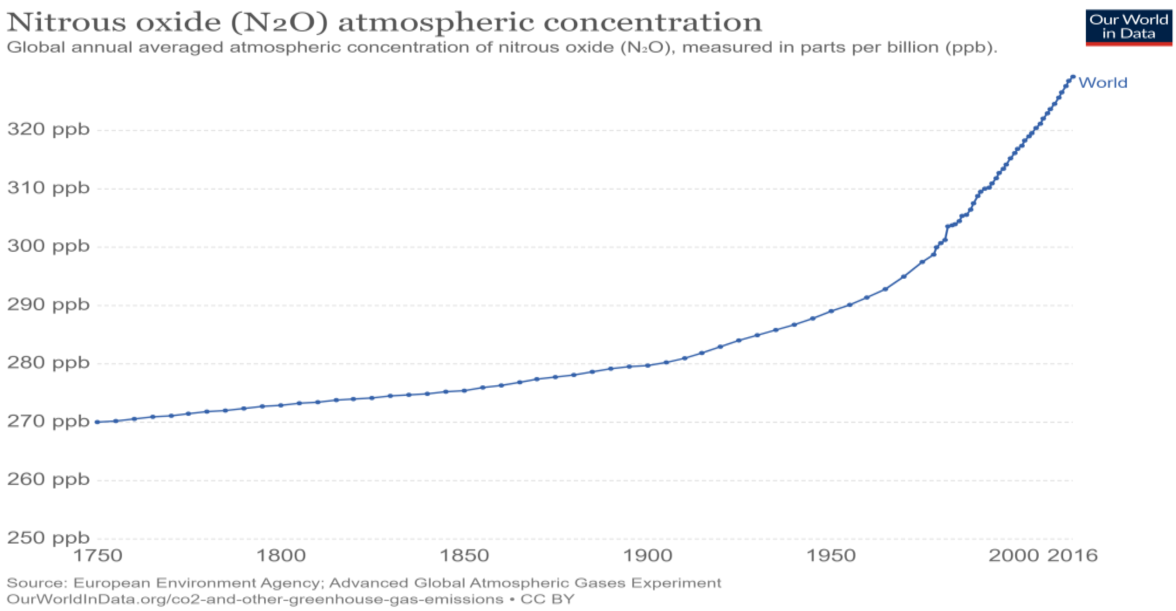


Figure 3 - Global N2O atmospheric concentration

Before the Industrial Revolution, the concentration of nitrous oxide reached 270ppb, while today it exceeds 320ppb. Today it is growing at a rate of about 0.2% per year. This means that by 2035 the concentration of nitrous oxide will reach 350ppb.

2.3 Global Warming

With the term “global warming”, we are referring to the increase in the average temperature of the oceans, the air, and the surface of the Earth. The increase in temperature is associated with an increase in the concentration of greenhouse gases in the atmosphere.

According to the Intergovernmental’s Panel on Climate Change (IPCC) 5th Assessment, "Human influence is very likely to be the leading cause of global warming since the mid-20th century."

The phenomenon is intensifying at the time of the Industrial Revolution, where the transition from human labor to machinery is taking place. Since that time there has been a huge increase in the specific gases due to human activity.

In the years following the Industrial Revolution, the planet's temperature continued to rise rapidly. Research done at various institutes around the world show that the planet's temperature has risen by 0.8 ° C since 1880. Still, it is possible that between 1990-2100 the temperature may rise by 1.4 ° C to 5 ° C.

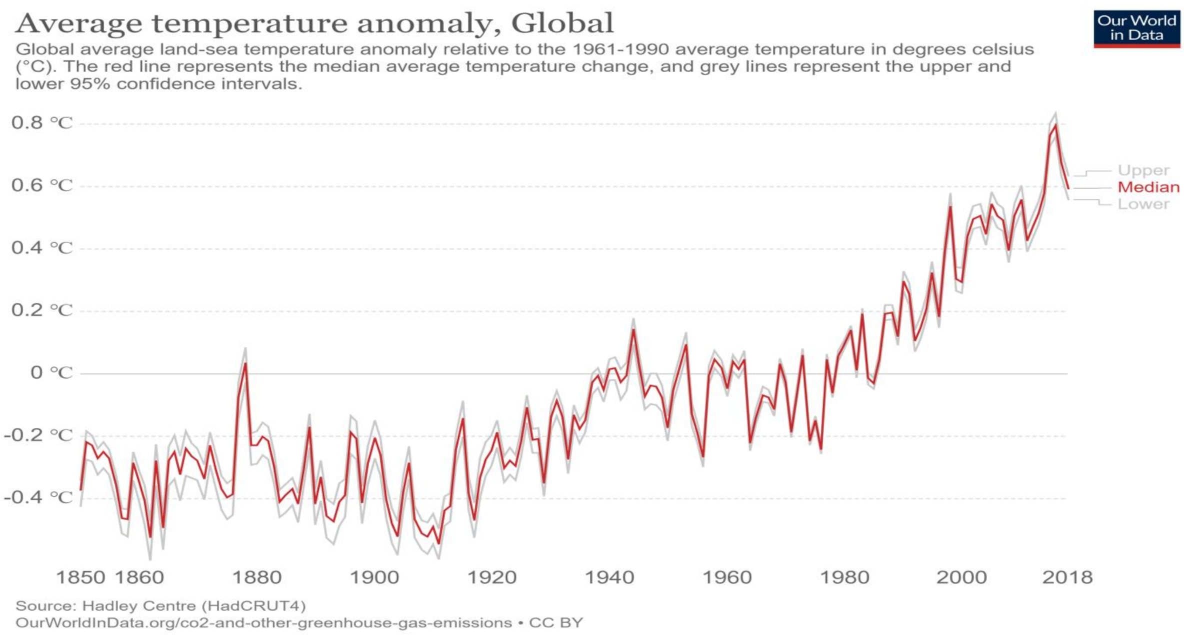


Figure 4 - Global average temperature anomaly

This change of 1 ° C over the past 100 years may seem insignificant, but it can cause significant problems such as rising sea levels, extreme weather events (e.g. floods, heat waves), etc.

Mobilizing to eliminate the phenomenon and reduce gas emissions is greater than ever. With the most well-known action plan, the Paris Agreement (2015), where leaders set the goal of limiting the global average temperature rise to 1.5 ° C.

Chapter 3: European Union Emissions Trading System

(EU ETS)

According to the Intergovernmental Panel on Climate Change, global emissions must be reduced to almost zero in order to stabilize the greenhouse gas stock in the atmosphere (IPCC, 2014). The International Society, having realized the magnitude of the problem of Climate Change, committed itself to reduce the increasing greenhouse gas emissions (mainly carbon dioxide, CO_2), through ambitious measures and objectives.

One of them is carbon pricing, which is implemented with two measures:

- Carbon Tax
- Greenhouse gas emissions trading system (GHG ETS)

Greenhouse Gas Emissions Trading System (GHG ETS)

"Cap & Trade" System (CAT)

Each government sets a cap on greenhouse gas emissions that various sectors can emit, usually 1 ton of carbon dioxide (1 tCO_2) per source. Then, each government allocates allowances for a given pollutant's emission rights. Polluters are required to hold allowances equal to their emissions. If someone does not wish to meet the limit of their emissions, they may sell some of them. Or even, if someone wants to increase their emissions, they can buy a license from someone who wants to sell it. So, emissions are tradable between states, organizations etc. Thus, the CAT system is a form of a flexible environmental policy. (Example: EU Emissions Trading)

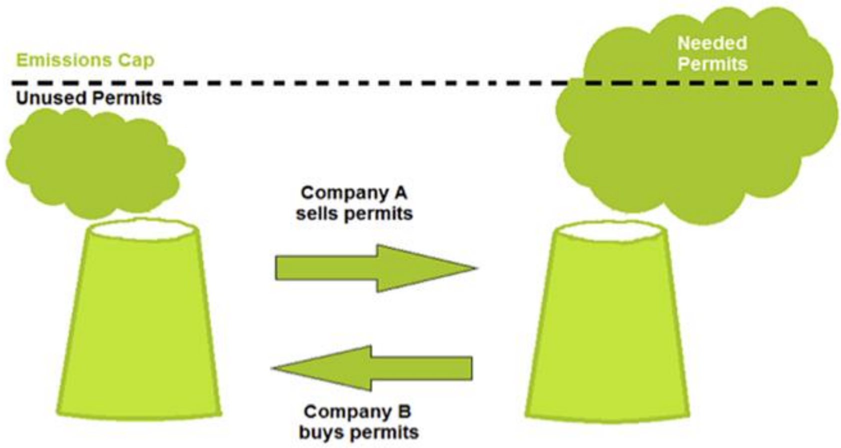


Image 1 - "Cap & Trade" System

“Baseline & Credit” System (BC)

In this case, a specific baseline- which is usually the level of a given year's emissions of the past - is set for each participant. Participants whose emission limit was lower than their actual emissions are allowed to have tradable allowances. If a participant has exceeded his emission limit, he has the opportunity to purchase credits to cover his emissions surplus. The BC system establishes an 'absolute' emissions limit, or it’s based on the output or intensity of the emissions. (Example: NSW Greenhouse Abatement Scheme, Clean Development Mechanism, UK Emissions Trading System)

Pollution Tax

The pollution tax corresponds to the amount of actual emissions of each pollutant. The challenge, however, lies in setting the appropriate level of taxes. Ideally, the price would be equal to the cost of pollution caused to society. Of course, this is hard to appraise.

Of the 3 basic ETS systems, the most commonly used is the "Cap & Trade" system, with the other two being less common.

The ETS is a relatively new measure, it was first implemented with mandatory force in 2002, more than a decade since the Carbon Tax was first implemented in 1990. Since then, the number of jurisdictions that have adopted the ETS has been steadily increasing. In particular, 17 ETSs operate in 55 jurisdictions - either national or regional.

Following is a reference to the larger ETS, the European Union Emissions Trading System (EU ETS).

3.1 What is the EU ETS?

The EU ETS is the cornerstone of European Climate Change Policy. It is a system based on the institution of "Cap & Trade" and is by far the largest Emissions Trading System. It covers about 45% of the European Union's greenhouse gas emissions. It determines the total volume of greenhouse gas emissions in more than 11,000 power stations and industrial plants in 31 countries (oil refineries, combustion plants with ≥20 MW thermal rated input, cement clinker, ferrous metal production, glass production, pulp and paper production), as well as in recent years, and airlines operating between the countries of the EU ETS.

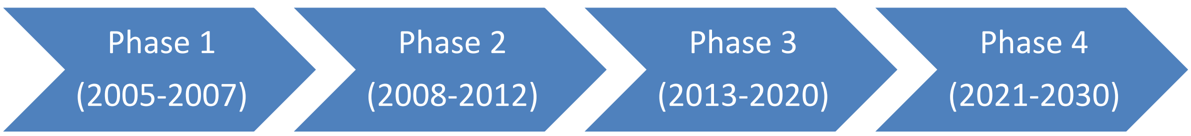
3.2 Phases of the EU ETS

In 1992, 180 countries unified fought against climate change and adopted an international treaty, the United Nations Framework Convention on Climate Change (UNFCC). Five years later, in 1997, they adopted the Kyoto Protocol. The 2 key pillars of the Kyoto Protocol, that formed the foundation for the EU ETS are:

1. Legally binding emission reduction targets for 37 industrialized countries
2. International Emissions Trading System (exchange of emission units between countries)

The first commitment period of the Kyoto Protocol started in 2008 and ended in 2012, while the second period began in 2013 and will expire in 2020. Today, 197 countries participate in the UNFCC and 192 in the Kyoto Protocol.

In 2000, the European Commission presented the Green Paper which title was "The greenhouse gas emissions trading in the European Union", which was a blueprint with initial ideas for the formation of the EU ETS. Following some necessary changes and additional planning, the EU Directive of the EU ETS was adopted in 2003 and launched in 2005 and has since undergone many changes. The system was implemented in different periods, also known as phases. Currently the EU ETS is in a transition from phase 3 (2013-2020) to phase 4 (2021-2030).



3.2.1 Phase 1 (2005-2007)

Phase 1 of the EU ETS is considered a 'pilot' phase and lasted three years, from 2005 to 2007. This phase was used to control the formation of prices on the carbon market and to create the necessary infrastructure for monitoring, reporting, and verifying emissions. It covered only carbon dioxide emissions from electricity and heat plants and industrial sectors based on high levels of energy, such as steel, iron, cement, oil etc. It also covered all 27 EU member states.

The caps were largely based on estimates, as there were no reliable data yet. Initially, the process of setting limits was decentralized. That is, each EU ETS Member State was able to propose its own national cap on carbon emissions, which, however, was inspected by the European Commission. This has motivated countries to be lenient to their EUAs (EU Emission Allowances) in order to protect their competitiveness in the financial sector. In Phase 1, EU ETS members distributed almost all their emission allowances (at least 95% of them). However, when real world emissions first began to be published, it became apparent that a plethora of allowances were issued, which led to an excess of emissions, which in turn led to a sharp drop in their prices (up to zero at the end of the period).

In 2006, it became clear that the allocation of allowances in 2005 had exceeded emissions by about 4% of the total amount. This overall-allocation of allowances has therefore led to a dramatic drop in their prices. Specifically, in January 2005 the price per ton of carbon dioxide was about € 8 / tCO_2, while in early 2006 it was over € 30 / tCO_2. At the beginning of April 2006, the price almost fell to the middle and a few months later it returned to 8 € / tCO_2. In the case of non-compliance, the penalty imposed was 40 € / tCO_2.

Figure 5 - EUAs price change (2005-2011)

The main contributors to this volatility are the lack of emission data at the beginning of the program, the volatility of the energy price, as well as the key feature of the program, which prevented the banking of allowances from phase 1 to phase 2.

However, while Phase 1 was a pilot phase for the institution of the European Union, it did manage to reduce emissions significantly. About 3% of the total emissions fell due to the first phase of EU ETS. This achievement is all the more remarkable given the fact that the program was created very quickly and with little information on actual greenhouse gas emissions.

Country	1st Phase Caps	Verified Emissions			Change
		2005	2006	2007	2005-2007
Austria	33.0	33.4	32.4	31.8	-4.9%
Belgium	62.1	55.37	54.78	52.6	-4.6%
Cyprus	5.7	5.1	5.3	5.4	6.2%
Czech Republic	97.6	82.46	83.63	87.84	6.5%
Denmark	33.5	26.48	34.2	29.4	11.1%
Estonia	19	12.62	12.1	15.33	21.5%
Finland	45.5	33.1	44.62	42.54	28.5%
France	156.5	131.3	127	126.7	-3.5%
Germany	499	475	478	487	2.5%
Greece	74.4	71.3	70	72.7	2.0%
Hungary	31.3	26	25.9	26.9	2.6%
Ireland	22.3	22.45	21.7	21.25	-5.3%
Italy	223.1	226	227.5	226.4	0.2%
Latvia	4.6	2.9	2.95	2.85	-0.2%
Lithuania	12.3	6.6	6.52	6	-9.2%
Luxembourg	3.4	2.6	2.72	2.57	-1.4%
Netherlands	95.3	80.35	76.7	79.9	-0.6%
Poland	239.1	203.1	209.7	209.6	3.2%
Portugal	38.9	36.4	33.1	31.2	-14.4%
Slovakia	30.5	25.2	25.54	24.52	-2.8%
Slovenia	8.8	8.7	8.84	9.1	3.8%
Spain	174.4	183.6	179.7	186.5	1.6%
Sweden	22.9	19.4	19.9	15.35	-20.8%
United Kingdom	245.3	242.5	251.2	256.6	5.8%
TOTAL	**2178.5**	**2011.93**	**2034**	**2050.05**	**1.9%**

Table 1 - Emissions in million tons of EU Member States on the first phase

The number of Member States was 27 in 2005-2007 (no information available on the following Member States: Romania, Bulgaria, Malta).

The overall increase in emissions over this period was 1.9%. This result is mainly due to national governments' initiatives to raise the thresholds, as they have exploited the system to increase their country's competitiveness by increasing their emission limits.

3.2.2 Phase 2 (2008-2012)

Phase 2 of the EU ETS started in 2008 and ended in 2012. It coincided with the first commitment period under the Kyoto Protocol. There have been several modifications to Phase 1 (2005-2007). The scope of Phase 2 covered additional sectors in Bulgaria and Romania, as well as 3 new non-EU countries who participate in the EU ETS, Iceland, Liechtenstein, and Norway. Furthermore, other greenhouse gases other than carbon dioxide, such as nitrogen oxide, derived from nitric acid production, are also covered. In addition, the second phase of the EU ETS has also included the aviation sector since 2012, but only for intra-European flights.

Also, in this phase, the number of granted allowances (EUAs) is decided at national level. The process of allocating national licenses has become more transparent and simpler through the adoption of a guidance document by the European Commission. While in Phase 1, 95% of allowances were distributed free of charge between states and 5% could be auctioned, Phase 2 reduced the proportion of allowances to 90% and the percentage of allowances that could be auctioned increased to 10%. Also, the cap in Phase 2 was reduced by 6.5% compared to Phase 1. And it was allowed to bank allowances from phase 2 to phase 3.

According to Figure 5, there is a sharp change in prices throughout Phase 2. Specifically, in the first half of 2008 allowances prices were in the range of € 20 / tCO_2, while in the second half of 2008 the average price was € 24 / tCO_2. In the first half of 2009 the price fell sharply to 15 € / tCO_2. In the fall of 2011, the price drops to 10 € / tCO_2, as the financial crisis has led to reduced demand for allowances, due to the reduced production of energy-intensive sectors. In the case of non-compliance, the penalty imposed was 100 € / tCO_2.

Country	Cap (state request)	Cap allowed	Additional Emissions in 2008-2012
Austria	32.8	30.7 (93.6%)	0.35
Belgium	63.3	58.5 (92.4%)	5.0
Bulgaria	67.6	42.3 (62.6%)	n.a.*
Cyprus	7.12	5.48 (77%)	n.a.
Czech Republic	101.9	86.8 (85.2%)	n.a.
Denmark	24.5	24.5 (100%)	0
Estonia	24.38	12.72 (52.2%)	0.31
Finland	39.6	37.6 (94.8%)	0.4
France	132.8	132.8 (100%)	5.1
Hungary	30.7	26.9 (87.6%)	1.43
Germany	482	453.1 (94%)	11.0

Greece	75.5	69.1 (91.5%)	n.a.
Ireland	22.6	22.3 (98.6%)	n.a.
Italy	209	195.8 (93.7%)	n.k.**
Latvia	7.7	3.43 (44.5%)	n.a.
Lithuania	16.6	8.8 (53%)	0.05
Luxembourg	3.95	2.5 (63%)	n.a.
Malta	2.96	2.1 (71%)	n.a.
Netherlands	90.4	85.8 (94.9%)	4.0
Poland	284.6	208.5 (73.3%)	6.3
Portugal	35.9	34.8 (96.9%)	0.77
Romania	95.7	75.9 (79.3%)	n.a.
Slovakia	41.3	30.9 (74.8%)	1.7
Slovenia	8.3	8.3 (100%)	n.a.
Spain	152.7	152.3 (99.7%)	6.7
Sweden	25.2	22.8 (90.5%)	2.0
United Kingdom	246.2	246.2 (100%)	9.5
TOTAL	**2325.34**	**2080.93 (89.5%)**	**54.61**

Table 2 - Emissions in million tons of EU Member States on the second phase

*n.a. not available

**n.k. not known

3.2.3 Phase 3 (2013-2020)

The third phase of the EU ETS started in 2013 and will end in 2020. This coincides with the second commitment period of the Kyoto Protocol, adopted in Doha on December 2012. At this period, we have the addition of another country, Croatia, at the beginning of Phase 3 in 2013. And more gases and sectors were added.

A key difference from Phase 1 and Phase 2 is that the decentralized policy adopted by the EU ETS for the distribution of allowances does not apply any more. States are not required to prepare national allocation plans for allowances, but an overall EU cap is set, subjected to the Linear Reduction Factor (LRF) of 1.4% per annum, is aimed at a 21% reduction in emissions in 2020, compared to 2005.

The main method of allocating allowances is by auction, in contrast to the earlier phases, where allowances were mainly distributed free of charge. Regarding the auction process, it is done at national level, but is regulated by the EU ETS Auctioning Regulation. The basic function of the Regulation is to ensure that national auctions operate in an open, transparent, harmonized and non-discriminatory manner.

Also, energy sectors are not eligible at this stage for free allocation of allowances, with some exemptions related to the modernization of electricity provided for in Article 10c of the EU ETS Directive. However, industries are entitled to free allocation of allowances based on benchmarks (BMs). There is an index for each material, such as steel, cement or lime, and it specifies the number of allowances that are distributed free of charge.

It is important to emphasize the availability of millions of allowances to the NER (New Entrants Reserve) to finance the development of innovative renewable energy technologies and the capture and storage of carbon dioxide through the NER300 program. The NER300 is one of the world's largest funding programs for innovative low-carbon demonstration projects.

As mentioned above, Phase 2 has permitted the banking of allowances from Phase 2 to Phase 3. Specifically, the number of allowances 'transferred' from one phase to another was 1.7 billion. This large surplus of allowances from Phase 2 to Phase 3 resulted in the price falling to around 3-7 € / tCO_2. As a measure to tackle the problem, the EU decided to postpone the auctions for 900 million licenses at the end of the period. In addition, the European Commission has proposed the implementation of the Market Stability Reserve (MSR), thereby balancing demand and supply of allowances.

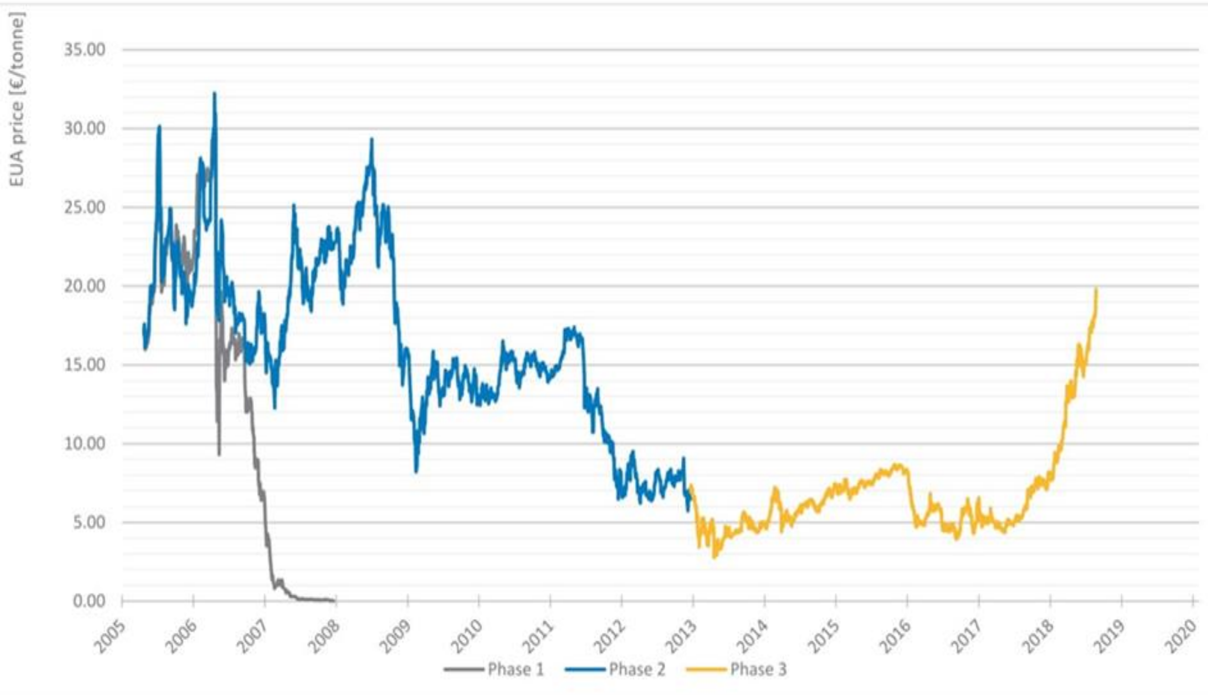


Figure 6 - EUAs price change (2005-2019)

3.2.4 Phase 4 (2021-2030)

The 4th phase of the EU ETS will start in 2021 and end in 2030. The 4th phase legislative framework has been revised in 2018 to add further measures and objectives as part of the EU contribution to the Paris Agreement.

The revision focuses on:

Firstly, the key objective of the forthcoming period is to reduce EU ETS emissions by 43% compared to 2005 levels. To achieve this, the total number of allowances must be reduced by 2.2% per year, compared to the 1.4% annual reduction in Phase 3. Therefore, by reducing the LRF, emissions during the 4th phase will decrease by approximately 556 million tons.

Secondly, there will be a strengthening of the MSR (Market Stability Reserve). It is envisaged to double the MRS take-up rate for faster absorption of carbon surplus emissions. Specifically, between 2019 and 2023, the number of allowances available in the reserve will double to 24% of total allowances. It was also decided that the number of allowances held in reserve would be limited to the number of allowances auctioned last year. If the number of allowances exceeds this amount, then they will lose their validity.

Thirdly, there will be free allowances allocation in sectors with a high risk of relocating their production outside the EU and will receive 100% of their free distribution. In contrast, sectors with low risk of relocating the free allocation will initially be eliminated from a maximum of 30% to 0 at the end of phase 4. In addition, new and developing facilities will receive free allowances. These allowances will come from allowances that were not distributed free of charge by the end of Phase 3, as well as 200 million allowances in reserve (MSR).

Finally, there will be funding in high energy intensive industrial sectors and in general energy sectors. The EU institution has come up with this measure seeking to encourage these sectors to respond to the innovation and investment challenges of the transition to a low carbon economy. The EU developed two main funds:

- <u>Innovation Fund</u>

  It supports the demonstration of innovative technologies in the industry sector

- <u>Modernization Fund</u>

  It invests in the modernization of the energy sector

3.3 Countries, sectors, gases and caps covered by the EU ETS

Countries

In the pilot phase, in 2005, the EU ETS started with 25 Member States and later in 2007 Romania and Bulgaria joined. At the end of the 1st period the program had 27 Member States. In Phase 2, the program was expanded with the addition of three new non-EU countries, Norway, Iceland and Liechtenstein. Finally, Croatia was added in the third phase, a few months before its formal accession to the EU.

Sectors

From phase 1, the EU ETS covered emissions from most energy and manufacturing sectors. At the end of the 2nd period, its scope was extended to cover carbon dioxide emissions from the aviation sector. From the 3rd period it also included the sectors of aluminum, carbon capture and storage, petrochemicals, and other chemicals.

Greenhouse Gases

Phase 1 of EU ETS only covers CO_2 emissions. From phase 2, the greenhouse gases covered by the program included N_2O (if the state chooses to include it). Phase 3 covers CO_2 emissions, N_2O emissions from the production of nitric, adipic and glyoxylic acids production and PFC emissions from aluminum production.

Cap

In the 1st period, each state sets their cap. In the 2nd period, the state proposes a cap, which is evaluated by the European Commission. Finally, in Phase 3 the cap isn’t set at national level, but all the EU member states adopt a single EU-wide cap. This cap ensures that there will be a reduction in EU greenhouse gas emissions. by 20% compared to 1990 levels.

The Figure below shows that the cap in the EU ETS can be separated into two: a cap for stationary installations and a cap for the aviation sector.

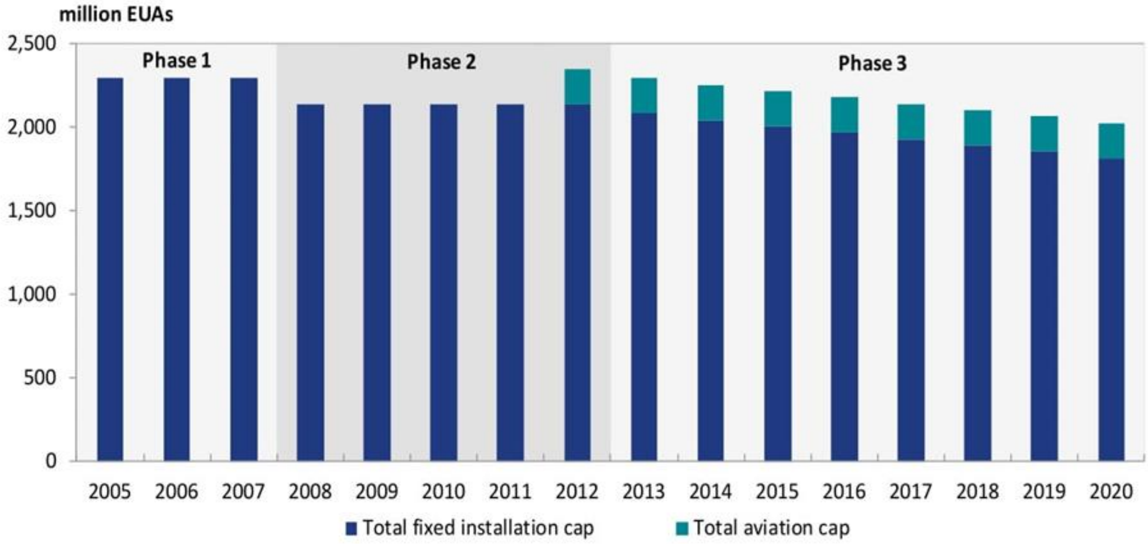


Figure 7 - Caps of phases and sectors

Features	Phase 1 (2005-2007)	Phase 2 (2008-2012)	Phase 3 (2013-2020)
Countries	➢ EU 27	➢ EU 27+ ➢ Norway ➢ Iceland ➢ Liechtenstein	➢ EU 27+ ➢ Norway ➢ Iceland ➢ Liechtenstein ➢ Croatia (since 2013)
Sectors	➢ Power stations and other combustion plants ≥20MW ➢ Oil refineries ➢ Coke ovens ➢ Iron and steel plants ➢ Cement clinker ➢ Glass ➢ Lime ➢ Bricks ➢ Ceramics ➢ Pulp ➢ Paper and board	➢ Same as Phase 1+ ➢ Aviation (from 2012)	➢ Same as phase 1 + ➢ Aluminium ➢ Petrochemicals ➢ Aviation (from 2014) ➢ Ammonia ➢ Nitric, adipic and glyoxylic acid production ➢ CO2 capture, transport in pipelines and geological storage of CO2
GHG	➢ CO_2	➢ CO_2 ➢ N_2O	➢ CO_2 ➢ N_2O ➢ PFC from aluminium production
Cap	2179 million tons	2081 million tons	2081 million tons (state request) + 55 million tons (additional emissions) = 2136 million tons (emissions of second phase) Decreasing in a linear way by 1.4% per year, almost 30 million tons less emissions each year

Table 3 - Features of each phase

3.4 Failure or a new efficient policy?

3.4.1 Environmental Effectiveness

The environmental effectiveness of the EU ETS system depends on the extent to which the environmental policy covers the key emitting sectors, the amount of the emission caps and whether the emission reduction was ultimately achieved.

Coverage of key emitting sectors

The EU ETS covers about 45% of greenhouse gas emissions.

Emissions cap and stringency

In the first two phases the caps are set by each Member State separately. Thus, the governments had the opportunity to increase their caps, in order to maintain their competitiveness. The problem, however, was solved by setting a wide-cap for emissions by phase 3, which would be reduced by 1.74% annually, while by phase 4 it would be reduced by 2.2% annually. The EU ETS also implemented the EU Transaction Log (EUTL), to track the trading of allowances of each Member State.

Emissions reduction achieved

Research indicates a 2.5-5% reduction in Phase 1 emissions and a 6.3% decrease in Phase 2. However, some researchers believe that most of the emission reductions are linked to the impact of the 2008 financial crisis. In Phase 3, there was a 2.9% decline from 2015 to 2016. It is anticipated that with new measures the EU ETS will further reduce emissions.

3.4.2 Economic efficiency

The economic efficiency of the EU ETS is assessed based on the marginal cost of abatement, the cost of compliance for firms regulated by the system and the cost of administrating the system. Emissions coverage under a market-based policy, such as the EU ETS, is likely to be more effective than non-ETS sectors.

3.4.3 Market management

In order to evaluate the performance of the allowance allocation, the current allocation method, the changes through the phases and the number of allowances auctioned, must be considered.

Allowance allocation

In Phases 1 and 2, allowances were mainly distributed free of charge, with a small percentage (3-5%) being auctioned. This percentage increased to 40% in the third phase.

Price stability

There was a sharp change in allowances' prices in the 1st and 2nd period due to the excess supply of allowances. The system responded to the problem with the creation of the MSR in phase 3. MSR acts as a tool that limits the amount of licenses, but not their price.

3.4.4 Revenue management

The EU ETS generated about $17 billion in auctions between 2012 and 2016, with at least 50% of the revenue distributed for climate- and energy-related purposes and for retrofitting existing infrastructure (European Commission, 2017).

Overall assessment	Attributes	Efficiency of EU ETS
Environmental Effectiveness	Coverage of key emitting sectors	Medium
	Emissions cap	Medium
	Stringency of cap	Medium
Economic Efficiency	Abatement cost	Medium
Market management	Method of current allocations	High
	Improved allocation practices over time	High
	Percentage auctioning	Medium
	Price stability	Low (phase 1 and 2) Medium (phase 3)
Revenue management	Revenue raised	High

Table 4 - Overall assessment of the EU ETS

So, does the EU ETS works or not?

From one point of view, the EU ETS program works, as emissions are reducing. Since it was implemented, Europe has been meeting its emission targets.

However, many have criticized this system for problems such as: over-allocation, windfall profits and in general for failing to meet its goals.

In any case, Europe has taken a very important initiative in tackling climate change and will certainly inspire other countries to design a similar system.

Chapter 4: Carbon Tax

The pricing of carbon dioxide emissions is considered as the main solution to global warming.

In the previous chapter, an analysis was made on one carbon pricing measure, the Greenhouse Gas Emissions Trading System, and in particular the European Union Emissions Trading System.

In the following chapter, we will analyze the second carbon pricing measure, the Carbon Tax.

4.1 What is a Carbon Tax?

Carbon Tax is a fee that the government imposes on every company that burns coal-based fuels (the main ones are: coal, oil, natural gas). It is the key policy to reduce and eventually eliminate the use of fossil fuels whose combustion is destabilizing and destroying the climate. It is a way for fossil fuel users to pay for the climate damage caused by the release of carbon dioxide into the atmosphere. Introducing a high tax incentivizes individuals to switch to clean energy, simply by making it more economical to use non-carbon fuels.

Unlike the Emissions Trading System, the Carbon Tax cannot guarantee a minimum level of greenhouse gas emissions reduction. But on the other hand, it can secure the price of carbon.

Still, some countries have adopted a hybrid approach, combining elements of an ETS and a Carbon Tax.

Also, a carbon tax is an indirect tax, that is, it does not tax income, as opposed to a direct tax. In economic theory, pollution is considered a negative externality (a negative effect on a third party, not directly involved in a transaction) and is considered as a type of "market failure". The tax on a negative externality is called the Pigovian tax (by economist Arthur Pigou) and equals the marginal damage cost.

The first carbon tax was implemented in 1990. As of 2019, over 40 countries have implemented carbon taxes. In January 2019, economists published a statement in The Wall Street Journal describing carbon tax as "the most cost-effective lever to reduce carbon emissions at the scale and speed that is necessary."

4.2 How is a Carbon Tax implemented?

Each government designates the emission sources subject to the tax and sets the tax rate per unit of emissions. Other greenhouse gases, other than carbon dioxide, can be expressed in tons of carbon dioxide equivalents (tCO_2). In this way, a tax can also cover emissions from other greenhouse gases other than carbon dioxide.

To be cost-effective the tax would cover all sources, and to be efficient, the carbon price would be set equal to the marginal benefits of emission reduction, represented by estimates of the social cost of carbon (Interagency Working Group on Social Cost of Carbon, 2010).

There are 2 types of carbon taxation:

1. “Upstream” Taxation

   Applying carbon tax to suppliers of fossil fuels based on the carbon content of fuel sales
2. “Downstream’ Taxation

   Applying carbon tax to final emitters at the point of energy generation

E.g. : in an application of "upstream" taxation, refineries and importers of petroleum products will pay a tax based on the carbon content of their gasoline, diesel fuel, or heating oil.

“Upstream” VS “Downstream”

‘Upstream” refers to the material inputs needed for production, while “Downstream” is the opposite end, where products get produced and distributed.

The tax rate can be set in a number of ways. It can be set equal to the estimated benefit of reducing greenhouse gas emissions or set the tax rate at a level that yields a target emission reduction, based on economic modelling, or even set a tax rate at the level similar to that of other jurisdictions.

However, in order to maintain efficiency, the tax rate should be adjusted regularly for the effects of inflation, increases in real income, technological changes, changes in fossil fuel prices etc.

4.3 Which countries have Carbon Tax?

Jurisdiction	Year Launched	Share of Jurisdiction’s GHG Emissions Covered	Price in € (per tCO_2)	Price in US $ (per tCO_2)
Finland (FI)	1990	36%	€ 62.00	$ 73.11
Poland (PL)	1990	4%	€ 0.07	$ 0.08
Norway (NO)	1991	62%	€ 52.09	$ 61.42
Sweden (SE)	1991	40%	€ 112.08	$ 132.17
Denmark (DK)	1992	40%	€ 23.21	$ 27.37
Slovenia (SI)	1996	24%	€ 17.00	$ 20.05

Estonia (EE)	2000	3%	€ 2.00	$ 2.36
Latvia (LV)	2004	15%	€ 5.00	$ 5.90
Switzerland (CH)	2008	33%	€ 83.17	$ 98.08
Ireland (IE)	2010	49%	€ 20.00	$ 23.58
Iceland (IS)	2010	29%	€ 27.38	$ 32.29
Ukraine (UA)	2010	71%	€ 0.33	$ 0.39
United Kingdom (GB)	2013	32%	€ 20.34	$ 23.99
France (FR)	2014	35%	€ 44.60	$ 52.59
Spain (ES)	2014	3%	€ 15.00	$ 17.69
Portugal (PT)	2015	29%	€ 12.74	$ 15.02

Table 5 - Carbon Taxes in Europe

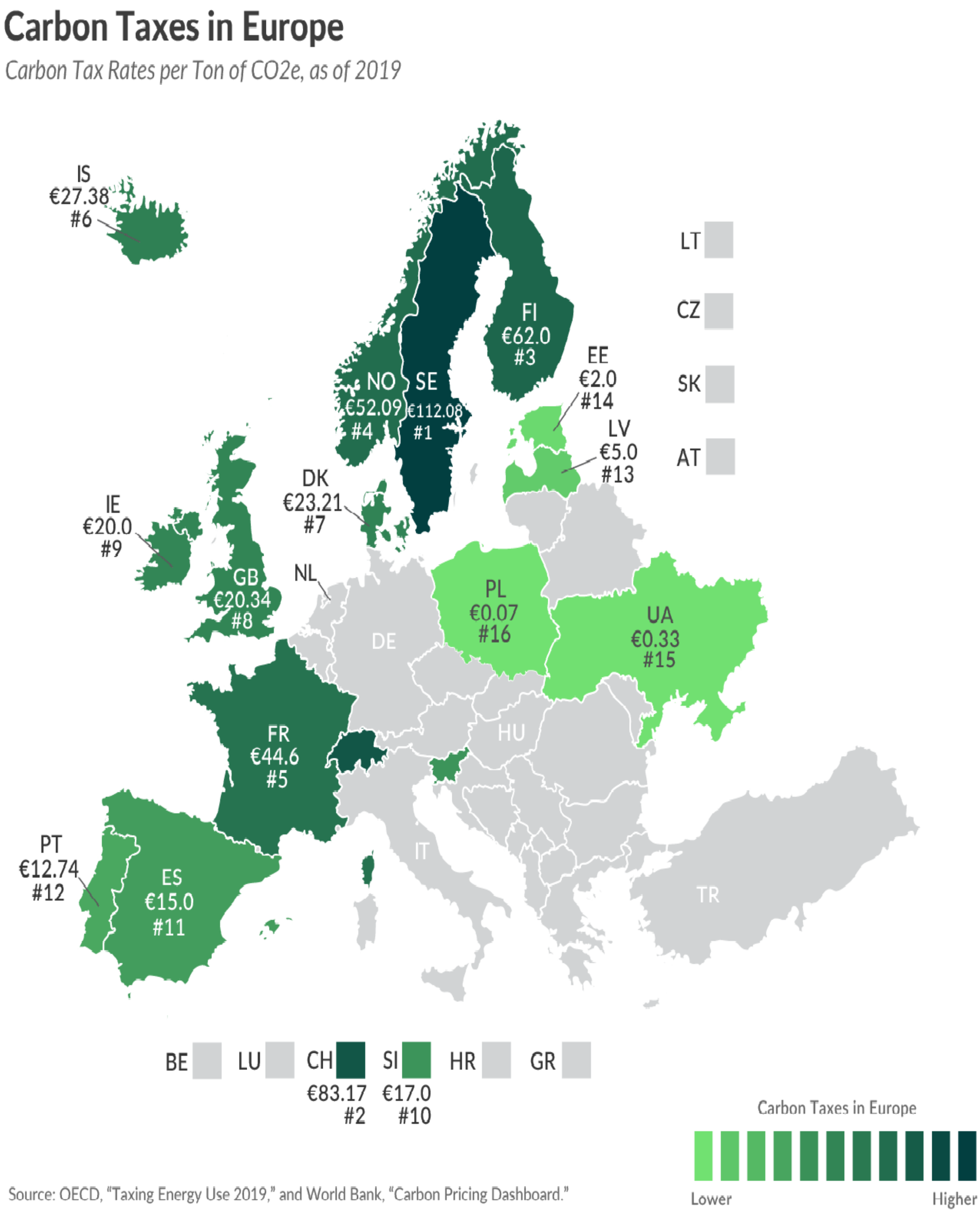


Image 2 - Carbon Taxes in Europe

With the exception of Switzerland and Ukraine, all other European countries that have adopted carbon tax are also members of the European Emissions Trading System (Switzerland has its own emissions trading system).

Sweden imposes the highest carbon tax at € 112.08 (US $ 132.17), per ton of carbon emissions. Next is Switzerland, with tax at € 83.17 (US $ 98.08) and Finland with tax at € 62.00 (US $ 73.11). The lowest taxes are in Poland at € 0.07 (US $ 0.08), Ukraine at € 0.33 (US $ 0.39) and Estonia at € 2.00 (US $ 2.36).

It appears from Table 5 that Spain covers only 3% of its emissions. This is due to the fact that the carbon tax it has implemented does not cover a plethora of gases, but only fluorinated gases. On the contrary, Norway covers 62% of its emissions, having recently abolished most of the exemptions and reduced rates.

Also, Catalonia (region of Spain) and the Netherlands are currently considering the implementation of a carbon tax.

It is worth mentioning, that Portugal ties its carbon tax rate to the previous year's EU ETS allowances price. But also, UK's carbon tax is tied to the EU ETS's allowances. The tax rate is determined as the difference between the EU ETS price and the UK's annual increasing carbon price floor target.

Here is an analysis of some countries that have implemented carbon tax.

4.3.1 The case of Norway

Norway implemented a carbon tax in 1991. This tax applies to about 60% of Norway's greenhouse gas emissions. Today, the average price of carbon tax is US $ 61.42 /tCO_2. In the transport sector, by 2009, Norway's carbon tax increased to US $ 58 /tCO_2 in gasoline and to US $ 34 /tCO_2 in diesel. The carbon tax on natural gas increased to US $ 33 /tCO_2. Also, the tax on coal used in power generation was US $ 24 /tCO_2, while for coal for coking purposes was US $ 19 /tCO_2. In addition, the carbon tax covered the oil and gas used in export activities in the North Sea. In 2003, Norway also applied a tax on HFCs (Hydrofluorocarbons) and PFCs (Perfluorinated gases) in equivalent tons of CO_2.

Norway's carbon tax is one of the highest taxes recorded in the Organization for Economic Cooperation and Development (OECD). In 2004, the International Energy Agency (IEA) estimated that carbon tax revenue amounted to about US $ 1.3 billion.

According to the IEA research, in 2005 carbon tax is the most important climate policy measure in Norway.

4.3.2 The case of Sweden

Sweden enacted a tax on carbon emissions in 1991. The original tax rate was US $ 33 /tCO_2, but by 2009 there has been a tax increase to US $ 135 /tCO_2. Today, the tax remains approximately at US $ 133 /tCO_2.

Unlike other countries, the carbon tax in Sweden does not apply to fuels used for electricity generation. Refineries, steel and other primary metal industries, as well as industries covered by the EU ETS, had received an exemption from the tax. Also, fuels from renewable energy sources such as ethanol, methane, biofuels, peat and waste are not covered by the tax. As a result, the tax has led to a large expansion of the use of biomass for heating and industry.

In the early 1990s, Sweden introduced taxes on oil and natural gas to charge for carbon and (for oil) sulfur dioxide and on coal-related sulfur dioxide and industrial nitrogen oxide emissions. These reforms were part of a broader tax-shifting operation that also strengthened the value-added taxes while reducing taxes on labor and traditional energy taxes (on motor fuels and other oil products).

Value-Added Tax (VAT) is a consumption tax placed on a product whenever value is added at each stage of the supply chain, from production to the point of sale.

Labor taxes include personal income tax, social security contributions paid by employees, and payroll taxes —that is, social security contributions and other taxes paid by the employer.

4.3.3 The case of Denmark

Denmark introduced its first carbon tax in 1992. Initially, the tax was US $ 18 /tCO_2, but around 2005 there was a slight decrease, with the tax then going to US $ 17 /tCO_2. Today, the tax rate is around US $ 27 /tCO_2.

In addition, manufacturing industries are subject to reduced tax rates of more than 90%, depending on their energy intensity and on whether the industry has a voluntary agreement to implement energy efficiency measures.

The main objective of the Danish government, with the implementation of a carbon tax, is to have people change their habits, because most of the money collected would be put into research for alternative energy resources.

4.3.4 The case of Finland

Finland was the first country to introduce a carbon tax in 1990. Today, the tax is around US $ 73 /tCO_2.

While initially based solely on carbon content, the process was converted into a combination of carbon tax and energy tax. This is due to the opening up of the Nordic Electricity Market because other Scandinavian countries excluded energy-intensive industries and the Finnish industries felt disadvantaged.

Finland also applied a border tax on imported electricity, which was later found not to comply with EU legislation for a single market.

Subsequently, there were changes to the carbon tax to exclude energy-intensive businesses, leading to increased reduction cost of carbon dioxide emissions.

4.3.5 The case of United Kingdom

The United Kingdom - England, Scotland, Wales, and Northern Ireland - has implemented a carbon tax since 2013. Today, the tax is around US $ 24 /tCO_2. Technically, the tax is a "carbon price floor", that functions as the minimum price that fossil fuel producers pay to emit CO2. Whenever the carbon price in the EU ETS is less than the UK minimum, then producers will pay the difference to the British Treasury. This tax is also called "top up" tax.

There has been a steady decline in UK's carbon dioxide emissions since 1990 and a steeper decline since 2013. A decrease has been observed in most sectors (transport, electricity, housing, industries, etc.), except for power stations. .

It is worth mentioning, that UK coal demand has fallen precipitously because of cheaper gas, the expansion of renewables, falling demand for energy and the closure of Redcar steelworks in late 2015. Perhaps the most consequential factor, however, is the UK's top-up carbon tax, which doubled in 2015 to £18 per ton of carbon dioxide.

4.4 Advantages and Disadvantages of the Carbon Tax

A carbon tax aims to make individuals and businesses pay the social costs of their pollution. In theory, the tax will reduce emissions and motivate individuals and businesses to look for alternative solutions. However, critics argue that implementing such a tax would increase cost for businesses and reduce investment and economic growth.

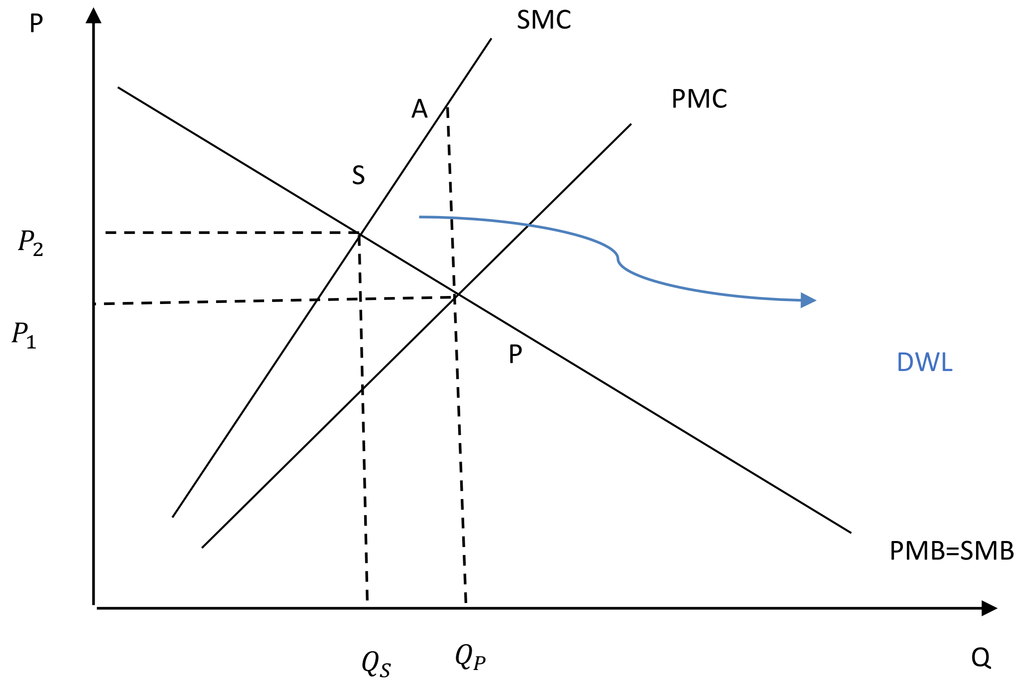


Figure 8 - Welfare loss of a negative externality

The SMC curve shows the social marginal cost. The PMC curve shows the private marginal cost. In the case of negative externality, PMB = SMB the private marginal benefit is equal to the social marginal benefit.

When there is a negative externality, it is privately produced greater than the optimal social quantity ($Q_P > Q_S$).

We have: **SMC> PMC = PMB = SMB**

The equilibrium of the society, if there is no state intervention (e.g. tax), is at P. Thus, a society that has not imposed any taxes has an excessive consumption Q (Q_P), which leads to loss of social welfare.

In the figure, Dead-weight loss is the triangle $\widehat{SAP}$.

In the following figure, we depart from the original balance at P (excluding tax) and go to the new balance at S (with tax).

With tax, consumers - in this case individuals and businesses - now face the full social cost (SMC).

With taxation, at the new equilibrium at S the quantity is less than the original equilibrium at P. The quantity Q_S is socially efficient because social marginal cost equals social marginal benefit (SMC = SMB).

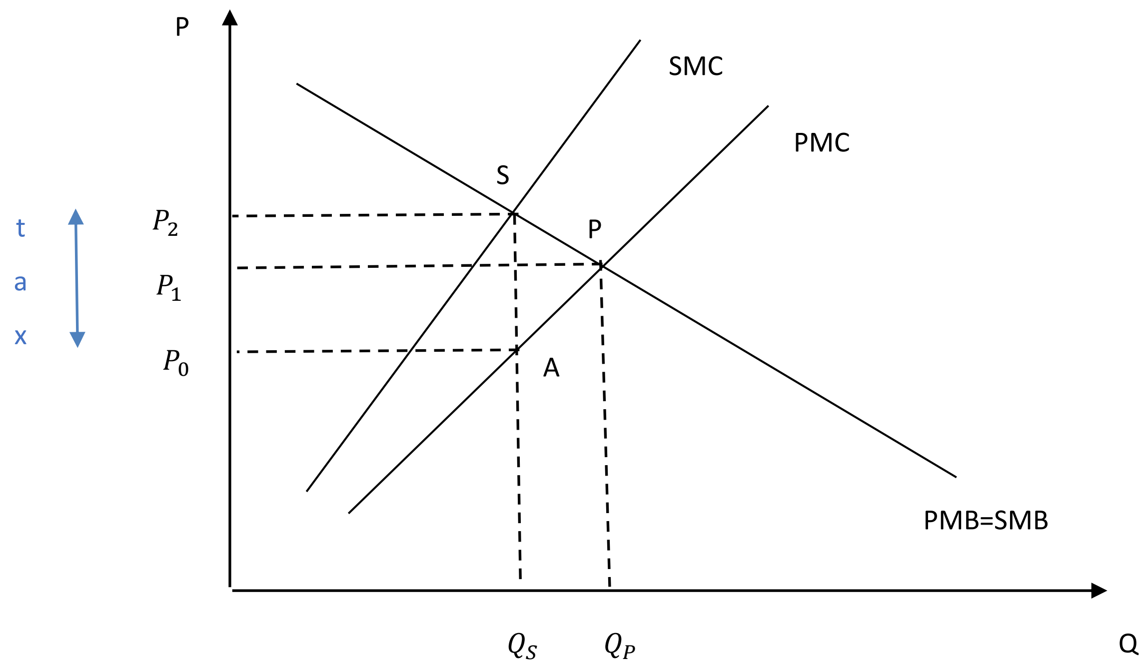


Figure 9 – Social Efficiency with carbon tax

Advantages:

1. <u>The carbon tax is paid by the polluters</u>

   So, to reduce emissions of pollutants into the air and tax revenue to be spent on research and development of clean fuel technologies.

2. <u>Carbon tax can contribute to the growth of the economy</u>

   Increasing GDP (Gross Domestic Product) and reducing emissions.

3. <u>Increase in revenue due to the implementation of carbon tax</u>

   Revenues could be funneled research into development of renewable energy technologies.

4. <u>Encourages the development of alternative energy sources</u>

   Carbon tax motivates individuals and businesses to look for new sources of energy (e.g. wind, solar, etc.).

Disadvantages:

1. Carbon-based fuels are widespread

   The problem with the carbon tax is that almost no one uses some form of renewable energy, regularly.
2. Moving production to a non-tax nation

   In 2017, jurisdictions that had adopted a carbon tax accounted for about 15% of total greenhouse gas emissions. This means that 85% of emissions are not taxed. When a jurisdiction announces the application of a carbon tax, the first thing a business does is to consider alternative sites and solutions.
3. Burden to the average consumer

   In the end, does the carbon tax target the biggest polluters or is the average consumer paying the final cost?
4. High administration cost

   The tax collection costs many millions.
5. Carbon reserves turn into something worthless

   There are countries, such as the US, that have accumulated stocks to supply up to 400 years of energy production. If the carbon tax continues to rise, there is a high chance that the value of carbon will deteriorate. This is expected to happen, as we hope that in the future fossil fuels will be replaced by renewable energy sources.

With better structuring, rectification, fewer loopholes and taking into account the interests of ordinary citizens and not only of large corporations, carbon tax may become the most efficient environmental policy measure and cause individuals to look for new sources of energy.

4.5 Carbon Tax VS EU ETS

Many believe that the EU emissions cap is not enough in the EU and that a tax is needed to achieve its environmental goals. It needs a high carbon price that will lead to major changes in energy planning, which the EU ETS does not.

On the other hand, a carbon tax is less flexible on environmental changes and will keep prices at a high level.

Figure 10 - Comparison between the EU ETS and carbon tax

However, its application throughout the EU, would take many years since all Member States would have to agree on its implementation.

It may be worth considering how little years the EU has been in operation and that maybe the future holds great changes in the way we protect the environment.

Chapter 5: Panel Data Analysis

In this study were used, the following European Union countries: Austria, Belgium, France, Germany, Denmark, Greece, Estonia, Ireland, Spain, Italy, Netherlands, Croatia, Cyprus, Latvia, Lithuania, Luxembourg, Malta, Hungary, Poland, Portugal, Romania, Slovakia, Slovenia, Sweden, Czech Republic (Czechia), Finland + United Kingdom (Brexit, 2019).

For evaluating this model, we used panel data analysis. Panel data models provide information on individual behavior, both across individuals and over time. The data and models have both cross-sectional and time-series dimensions. The cross-section units are the EU countries, while the time series consists of 9 years, from 2009 to 2018. The Ordinary Least Squares (OLS) was chosen as the data panel estimation method.

5.1 Panel Data

A panel data (or longitudinal data) is a multi-dimensional data of an observation that is measured repeatedly over time. It is balanced when all individuals are observed in all time periods or unbalanced when individuals are not observed in all time periods.

There are many advantages to using panel data, such as allowing the lack of homogeneity between economic units to be taken into account, by analyzing the dynamics of the data over time, maintaining heterogeneity in the characteristics of each unit. On the contrary, time series ignore the difference in characteristics and can lead to biased conclusions, while panel data allows both static and dynamic interdependencies to be considered. Also, this method allows us to check for factors that may change -but not over time- or for factors that cause bias due to an oversight of variables.

Bias: the difference between the expected value of an estimator and the population value that the estimator is supposed to be estimating.

In addition, the method allows the empirical analysis of more complex theoretical models and bypasses the main problem of the cross-sectional data, which is heteroskedasticity. The use of panel data contains more information about each entity, which leads to the improvement of the estimated coefficients and helps to reduce the multicollinearity, making the research more consistent.

Heteroskedasticity: the variance of the error term, given the explanatory variables, is not constant

Multicollinearity: a term that refers to correlation among the independent variables in a multiple regression model, it is usually invoked when some correlations are "large," but an actual magnitude is not well defined

However, the method also has disadvantages. Initially, it is difficult to design such a survey and collect a large number of statistical data. In addition, errors in data measurements may occur or even errors in collecting and recording statistical observations.

Basic Model

In panel analysis, the basic model is formulated as follows:

$$Y_{it} = a_0 + a_1 X_{it,1} + a_2 X_{it,2} + \cdots + a_k X_{it,k} + u$$

Y_{it}: is the observation of the unit *i* of the dependent variable *Y*

for $i = 1,2,3, \ldots N$ and $t = 1,2,3, \ldots . T$

$x_{i,t,k}$: is the i^{th} (or t^{th}) observation of the independent variable x_k

for $i = 1,2,3,\ldots,N$ $t = 1,2,3,\ldots,T$ and $j = 1,2,3,\ldots,K$

u: error term

5.2 Ordinary Least Squares (OLS)

For the estimation of the model we use the Ordinary Least Squares method. OLS is a method for estimating the parameters of a multiple linear regression model. The ordinary least squares estimates are obtained by minimizing the sum of squared residuals. That way, the sum of the squared residuals from the regression is minimal. The OLS method determines the line that approaches the points in the dispersion diagram as much as possible.

In order to better adapt the model to the data, the coefficient of determination is calculated (R^2) based on the regression model. The coefficient of determination is a measure of the model's ability to adapt. Regardless of the number of explanatory variables, the coefficient of determination is defined as the ratio of the variability of the dependent variable interpreted by the regression, that is, by the independent variables. The coefficient of determination takes values in space (0,1). The closer the R^2 is to 1, the better the model approaches and interprets the dependent variable.

Coefficient of determination – R^2: in a multiple regression model, the proportion of the total sample variation in the dependent variable that is explained by the independent variable.

The value of the coefficient of determination is affected -directly- by the number of independent variables in the model. If the sample has a small number of observations and a large number of explanatory variables, there is a problem of consistency and accuracy of the estimators.

To correct this problem, we use the adjusted coefficient of determination. Their main difference is that if a new variable is added to the model, the coefficient of determination will increase, regardless of whether the new variable contributes significantly or not to the explanatory variable, while the adjusted coefficient of determination may increase or decrease accordingly, so it is more consistent.

The formula for $\bar{R}^2$ is defined as,

$$\bar{R}^2 = 1 - (1 - R^2) \left[\frac{n-1}{n-(k+1)}\right]$$

n : sample size

R^2 : coefficient of determination

k : number of independent variables

The adjusted coefficient of determination is always less than or equal to the coefficient of determination.

<u>Adjusted coefficient of determination - $\bar{R}^2$</u>: a goodness-of-fit measure in multiple regression analysis that penalizes additional explanatory variables by using a degrees of freedom adjustment in estimating the error variance

<u>Consistency</u>: an estimator converges in probability to the correct population value as the sample size grows.

To determine if the model is suitable for interpreting the dependent variable, we use the F-test. The result of the criteria arises from the regression and if its critical value is statistically significant then the model is suitable to interpret the variability of the dependent variable.

<u>Critical value</u>: in hypothesis testing, the value against which a test statistic is compared to determine whether or not the null hypothesis is rejected.

5.3 The Model

The initial goal of this study is to examine the relationship between renewable energy sources and taxes imposed for environmental protection. Specifically, how taxes affect individuals or businesses to turn to renewable energy sources.

The model is as follows:

log (Y) = A F(P, N, E, T, K)

Y = Share of renewable energy sources

P = Pollution taxes in million euros

N = Total Environmental taxes in million euros

E = Energy taxes in million euros

T = Transportation taxes in million euros

K = Total environmental protection expenditures in million euros

5.4 Basic equation and description of the variables

The equation that we will use will try to explain how the use of renewable energy sources is affected by pollution taxes, total environmental taxes, energy taxes, transportation taxes and by expenditures for environmental protection.

The equation is:

$$\widehat{log\ (Y)} = b_0 + b_1*\hat{P} + b_2*\hat{N} + b_3*\hat{E} + b_4*\hat{T} + b_5*\hat{K}$$

This equation is about a Log-Level Regression.

Specifically,

$log\ (y) = b_0 + b_1\ x + u$

dependent variable: log (y)

independent variable: x

interpretation of b_1: if we change x by 1 (unit) we would expect our y variable to change by 100 b_1 %

$$\%\ Dy = 100\ b_1\ Dx$$

5.5 Results

Table 6 shows that, on average, the countries participating in the survey collect, over a period of 9 years, pollution taxes equal to 412.5 million euro, with a deviation of 808.53. The maximum collection of pollution taxes is 3284 million euro and the minimum price is 0 euro, which indicates that there are one or more countries that do not collect pollution taxes.

Also, on average, countries collect total environmental taxes equal to 12178.1 million euro with a deviation of 17481,21. The maximum amount of the total environmental taxes collected by the countries that participated in the survey is equal to 63763.36 million euro and the minimum amount is equal to 190.62 million euro.

Furthermore, Table 6 shows that on average, the countries participating in the survey collect energy taxes equal to 9342.7 million euro with a deviation of 13946.51. The maximum amount of energy taxes collected is 49479 million euro and the minimum amount of energy taxes collected is 68.62 million euro.

The survey also shows that, on average, the countries participating in the survey collect transportation taxes equal to 2422.8 million euro, with a deviation of 3353.88. The maximum amount of transportation taxes collected is 14974.37 million euro and the minimum amount is 6.42 million euro.

In addition, Table 6 shows that on average the countries participating in the survey spend for environmental protection an amount equal to 5596.5 million euro with a deviation of 11301.25. The maximum expenditure for environmental protection is equal to 54933 million euro and the minimum is equal to 0 euro.

Finally, Table 6 shows that, on average, the countries participating in the survey have a percentage of renewable energy usage equal to 18.5 % with a deviation of 11.5 %. The maximum percentage of renewable energy usage is 54.65 % and the minimum percentage is 0.22 %.

We observe that all variables have a large standard deviation. The high standard deviation indicates that the data is "spread" over a wider range of prices.

	Minimum	Maximum	Mean	Std. Deviation
Pollution taxes in million euro	,00	3284,00	412,5484	808,53295
Total environmental taxes in million euro	190,62	63763,36	12178,0507	17481,20806
Energy taxes in million euro	86,62	49479,00	9342,6825	13946,51391

Transportation taxes in million euro	6,42	14974,37	2422,8202	3353,88158
Total environmental protection in million euro	,00	54933,00	5596,5146	11303,2485 1
Share of renewable energy	,22	54,65	18,4828	11,52252

Table 6 - Main descriptive elements of the variables

From Table 7 we conclude that there is a

- Moderate positive correlation between pollution taxes and total environmental taxes (r=0.544, p=0.00<0.01)
- Moderate positive correlation between pollution taxes and energy taxes (r = 0.485, p = 0.00 <0.01)
- Moderate positive correlation between pollution taxes and transportation taxes (r = 0.580, p = 0.00 <0.01
- Moderate positive correlation between pollution taxes and environmental protection expenditures (r = 0.318, p = 0.00 <0.01)
- Weak negative correlation between pollution taxes and renewable energy sources (r = -0.286, p = 0.00 <0.01)
- Strong positive correlation between total environmental taxes and energy taxes (r = 0.995, p = 0.00 <0.01)
- Strong positive correlation between total environmental taxes and transportation taxes (r = 0.944, p = 0.00 <0.01)
- Moderate positive correlation between total environmental taxes and total environmental protection expenditures (r = 0.671, p = 0.00 <0.01)
- Weak negative correlation between total environmental taxes and renewable energy sources (r = -0.203, p = 0.001 <0.01)
- Strong positive correlation between energy taxes and transportation taxes (r = 0.910, p = 0.00 <0.01)
- Moderate positive correlation between energy taxes and total expenditures for environmental protection (r = 0.684, p = 0.00 <0.01)

- Weak negative correlation between energy taxes and renewable energy sources (r = -0.190, p = 0.001 <0.01)
- Moderate positive correlation between transportation taxes and total environmental protection expenditures (r = 0.580, p = 0.00 <0.01)
- Weak negative correlation between transportation taxes and renewable energy sources (r = -0.198, p = 0.001 <0.1)
- Weak negative correlation between total environmental protection expenditures and renewable energy sources (r = -0.144, p = 0.024> 0.01)

Correlations

		Pollution taxes in million euro	Total environmental taxes in million euro	Energy taxes in million euro	Transportation taxes in million euro	Total environmental protection in euro	Share of renewable energy
Pollution taxes in million euro	Pearson Correlation	1	,544**	,485**	,580**	,318**	-,286**
	Sig. (2-tailed)		,000	,000	,000	,000	,000
Total environmental taxes in million euro	Pearson Correlation	,544**	1	,995**	,944**	,671**	-,203**
	Sig. (2-tailed)	,000		,000	,000	,000	,001
Energy taxes in million euro	Pearson Correlation	,485**	,995**	1	,910**	,684**	-,190**
	Sig. (2-tailed)	,000	,000		,000	,000	,001
Transportation taxes in million euro	Pearson Correlation	,580**	,944**	,910**	1	,580**	-,198**
	Sig. (2-tailed)	,000	,000	,000		,000	,001
Total environmental	Pearson Correlation	,318**	,671**	,684**	,580**	1	-,144*

protection in euro	Sig. (2-tailed)	,000	,000	,000	,000		,024
Share of renewable energy	Pearson Correlation	-,286**	-,203**	-,190**	-,198**	-,144*	1
	Sig. (2-tailed)	,000	,001	,001	,001	,024	
**Correlation is significant at the 0.01 level (2-tailed).							
*Correlation is significant at the 0.05 level (2-tailed).							

Table 7 - Variable correlation examination

Table 8 shows that the dependent variable (renewable energy sources) is interpreted by 13.8% of the independent variables of the model. The R^2 is low, so we conclude that the model does not adequately interpret the dependent variable.

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,371[a]	,138	,123	10,73564
a. Predictors: (Constant), Total environmental protection in euro, Pollution taxes in million-euro, Transportation taxes in million-euro, Energy taxes in million euro				

Table 8 - Interpretation of the model's dispersion

The following table shows that pollution taxes have a statistically significant effect on renewable energy sources (t = -3.734, p-value = 0.000 <5%). While energy taxes (t = 0.026, p-value = 0.979> 5%), transportation taxes (t = -0.962, p-value = 0.337> 5%) and total environmental protection expenditures (t = 0.385, p- value = 0.700> 5%) do not have a statistically significant effect on renewable energy sources.

A *p*-value less than 0.05 (typically ≤ 0.05) is statistically significant. It indicates strong evidence against the null hypothesis, as there is less than a 5% probability the null is correct (and the results are random). Therefore, we reject the null hypothesis, and accept the alternative hypothesis.

The model shown in Table 9 is:

$$\widehat{\log(Y)} = 21.743 - 0.004\,\hat{P}$$

(0.854) (0.001)

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	21,743	,854		25,449	,000
Pollution taxes in million euro	-,004	,001	-,275	-3,734	,000
Energy taxes in million euro	3,489	,000	,004	,026	,979
Transportation taxes in million euro	-,001	,001	-,158	-,962	,337
Total environmental protection in million euro	3,254	,000	,032	,385	,700
Dependent Variable: Share of renewable energy					

Table 9 - Coefficients

5.6 Conclusions

The main aim of this study is to examine the effect of various environmental taxes on the use of renewable energy sources. For the survey we study all the countries of the European Union (+ UK) from the year 2009 to 2018.

We conclude that, in general, variables have a high standard deviation, which means that there is a wide range of values in the model. Also, only pollution taxes have a statistically significant effect on the dependent variable. Finally, we conclude that there is a weak negative correlation between pollution taxes, total environmental taxes, energy taxes and transportation taxes with the rate of renewable energy sources usage. This means that when one variable increases, the other decreases, which in reality should not be the case. On the contrary, the more taxes the government imposes, the higher the rate of the renewable energy usage should be, as businesses or individuals choose cheaper solutions. This result, perhaps, can be explained by the small R^2 value, which suggests that the model does not adequately interpret the dependent variable.

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