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TESI DI LAUREA

# THE IMPACT OF $CO_2$ COST ON THE ITALIAN ELECTRICITY PRICE. A VECM ANALYSIS.

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*Alla mia famiglia*

SUMMARY

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# Introduction

On 11th December 1997, more than 150 nations signed and adopted the Kyoto Protocol, (United Nations 1998)[1], an international agreement that commits the participants to reduce greenhouse gas emissions. The protocol is based on the scientific consensus that climate change is happening and that it's extremely likely that human-made $CO_2$ emissions are predominantly causing it (Liverman 2009)[2].

The first commitment period of the treaty started in 2008 and ended in 2012. A second commitment period was agreed on in 2012, in which 37 countries, including the European Union and its 28 Member States, have binding targets, (United Nations 2011)[3]. This led the European Union to the need for policy instruments to meet the Kyoto commitments. In 2000 a green paper on "Greenhouse gas emissions trading within the European Union" was presented by the European Commission[4], this served as a basis for further discussions that helped to build the so-called European Emission Trading System (EU ETS), firstly introduced in 2005 (Ellerman and Buchner 2007)[5].

The EU Emissions Trading System is a "cap and trade" system in which the total volume of GHG emissions in the area are limited through the use of emission allowances. These allowances can be traded so that the least-cost measures can be taken up to reduce emissions. Despite the great number of positive results the system has achieved during the first period of its implementation (Laing et al, 2013)[6], some critical issues have however arisen (Brown, Hanafi and Petsonk 2012)[7], bringing to changes in the emission scheme as a whole.

[1] UNITED NATIONS. (1998). *Kyoto protocol to the united nations framework convention on climate change*. https://unfccc.int/resource/docs/convkp/kpeng.pdf

[2] LIVERMAN D.M. (2009). *Conventions of climate change: constructions of danger and the dispossession of the atmosphere*. Journal of Historical Geography 35: pp. 279-296.

[3] UNITED NATIONS. (2011). *Compilation and synthesis of fifth national communications*. https://unfccc.int/resource/docs/2011/sbi/eng/inf01.pdf

[4] EUROPEAN COMMISSION. (2000). *Green Paper on greenhouse gas emissions trading within the European Union*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52000DC0087

[5] ELLERMAN A.D., BUCHNER B.K. (2007). *The European Union Emissions Trading Scheme: Origins, Allocation and Early results*. Review of Environmental Economics and Policy: pp. 66-87.

[6] LAING T., SATO M., GRUBB M. and COMBERTI C. (2013). *Assessing the Effectiveness of the EU Emission Trading System*. Centre for Climate Change Economics and Policy, 126.

[7] BROWN L.M., HANAFI A. and PETSONK A. (2012). *The EU Emissions Trading System: Results and Lessons Learned.* https://www.edf.org/sites/default/files/EU_ETS_Lessons_Learned_Report_EDF.pdf

In fact, the price on carbon raises costs associated with pollution and this can impact the competitiveness of certain industrial sectors which compete with countries where lower levels of actions are taken to reduce the GHG pollution. This could lead companies to transfer their productions to other countries with laxer measures to cut pollutant emissions. While the free allocation of emissions allowances seems to be a feasible solution to this problem, in some sectors it had brought some distortive effects. For example, in the power market the experience of the first two trading periods showed that power generators were able to pass on the cost of emission allowances to costumers, even when they received them for free (Sijm, Neuhoff and Chen, 2011)[8]. This is the reason why in Phase III of the EU ETS, operators in the power market are no longer eligible to receive free allowances and have to buy them in auctions (European Commission, 2011)[9].

The aim of this study is to check whether such a change in the policy influenced the way in which the cost of the allowances is passed on the electricity price and the magnitude of this phenomenon. The study is conducted in the Italian power market where little analysis regarding the Emission Trading System has, so far, been carried out.

The dissertation is organized as follow. In the first chapter, the general characteristics of the EU Emissions Trading System are presented, underlining the benefits and results the scheme has achieved up to now. In the second chapter, the focus will shift to the power sector and to the way in which the allocation method of allowances has changed over the years. The third chapter will focus on the electricity power market; the electricity production mix of a country can in fact play an important role in the relationship between allowances price and power price. In the fourth and fifth chapter the empirical analysis is presented: through the Vector Error Correction Model we will analyze the impact of changes in the allowances price to the Italian electricity price. More precisely, in the former, data and the general model are described, in the latter we will report the methodology and the results obtained. Theoretical and empirical outcomes are then coped together in the final chapter.

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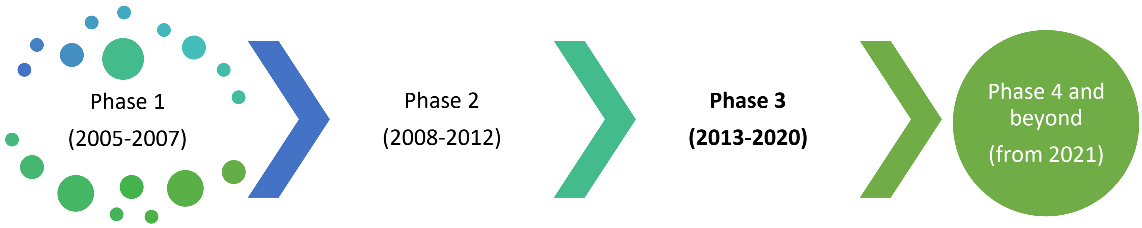
[8]SIJM J., NEUHOFF K. and CHEN Y. (2011). *$CO_2$ cost pass-through and windfall profits in the power sector*. Climate Policy, 6: pp 49-76.

[9] EUROPEAN COMMISSION. (2011). Commission decision of 29.03.2011 on guidance on the methodology to transitionally allocate free emission allowances to installations in respect of electricity pursuant to Article 10c(3) of Directive 2003/87/EC.
https://ec.europa.eu/clima/sites/clima/files/ets/allowances/electricity/docs/c_2011_1983_en.pdf

# 1. The Emissions Trading System

The Emissions Trading System (EU ETS) is a cap and trade system firstly introduced in the European area in the 2005. It is the main tool of the European Union to fight the climate change and to accomplish the reduction targets of the Kyoto protocol. The EU ETS is the biggest emission trading system whose aim is to reduce the greenhouse gas emissions, it covers more than 11.000 industrial plants and power stations in 31 countries and also flights between airports of the countries involved[10].

The mechanism has been implemented over time through distinct trading periods, known as phases. The current phase of the EU ETS is the third one: it started in 2013 and will last until 2020.




The first phase of the EU ETS, called also the pilot phase, ran the first two years, from 2005 to 2007. This phase had the main purposes of testing the price formation in the carbon market and establishing the necessary infrastructures for verifying, monitoring and reporting emissions. The aim of the pilot phase was therefore to ensure that Member States would have been able to meet their commitments. Firms could meet their obligations under the EU ETS through the use of certain emission reduction units generated under the Kyoto Protocol clean development mechanism (CDM)[11], as specified in the Directive 2004/101/EC[12].

[10] Source: the European Commission's page on the EU ETS https://ec.europa.eu/clima/policies/ets_en
[11] The *CDM* allows emission-reduction projects in developing countries to earn certified emission reduction (CER) credits, each equivalent to one tonne of CO2. These CERs can be traded and sold, and used by industrialized countries to meet a part of their emission reduction targets under the Kyoto Protocol.
[12]*Directive 2004/101/EC of the EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Directive 2003/87/EC establishing a scheme for greenhouse gas emission allowance trading within the Community, in respect of the Kyoto Protocol's project mechanism*. Official Journal of the European Union, 338/18.

The second phase of the EU ETS coincided with the first commitment period under the Kyoto Protocol, running from 2008 to 2012. In this period, also the emission reduction units generated by the joint implementation (JI)[13] could be used. This made the EU ETS the largest source of demand for the CDM and JI emission reduction units. Towards the end of this phase aviation was included in the scope of the EU ETS (Directive 2008/101/EC)[14]. This is also the period in which the EU set the so called "20-20-20" targets, a series of energy and climate targets to be met by 2020. These targets are meant to help the European Union to reach the primary objective of keeping climate change below the 2°C. They are:

- Reducing the GHG emissions of at least 20% below 1990 levels
- Reducing by 20% the primary energy use with respect to projected levels, to be achieved by improved energy efficiency
- Increasing the fraction of EU energy consumption coming from renewable sources of 20% or more.

With these goals in mind and the lessons learnt from the first two phases, the Emission Trading System has been shaped for the third phase. This phase is the current one as it runs from the end of 2012 to 2020 and it coincides with the second commitment period of the Kyoto Protocol.

The EU ETS doesn't have an end date and continues beyond this period, underlining the commitment of the EU to tackle climate change. The actual long-term objective is reducing greenhouse gas emissions by 80-95% with respect to 1990 levels (European Commission, 2018)[15].

## 1.1 How does it work

The main feature of the Emissions Trading System is that the total amount of GHG that can be produced by the installations covered by the system is capped. This cap is decreased over time so that the total emissions fall. Companies buy or receive emission allowances which can be traded if needed, each allowance represents a tonne of $CO_2$ that can be emitted by the company which owns it. At the end of a year, participants must give back an emission allowance for

https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32004L0101

13 Under Joint Implementation, countries with commitments under the Kyoto Protocol are eligible to transfer and/or acquire emission reduction units (ERUs) and use them to meet part of their emission reduction target.

14 Directive 2008/101/EC of the European Parliament and the Council amending Directive 2003/87/EC so as to include aviation activities in the scheme for greenhouse gas emission allowance trading within the Community. Official Journal of the European Union, 8/3. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32008L0101

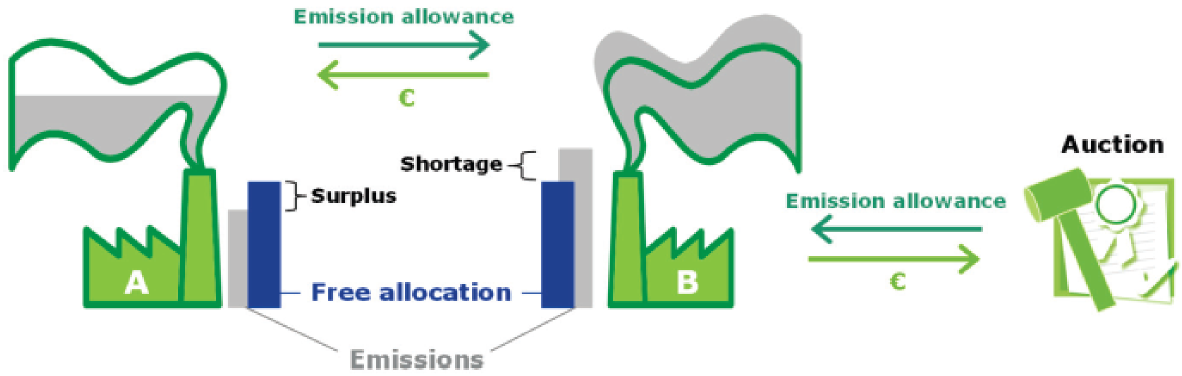
15 EUROPEAN COMMISSION. (2018). *The commission calls for a climate neutral Europe by 2050*. Brussels. http://europa.eu/rapid/press-release_IP-18-6543_en.htm

every tonne of $CO_2$ they have emitted during the year. If a business has insufficient allowances, then it must either buy more allowances on the market or take measures to reduce its emissions. Besides auctions, participants can buy and sell allowances from each other.

The limited or capped supply guarantees that emissions rights have a value and there is demand from those participants with a lower cost of making reductions. The system therefore incentives the effort to be redistributed between businesses so that emissions reductions take place to those sectors where it costs less.

If companies fail to surrender sufficient allowances in time, significant fines are imposed up to 100€/t$CO_2$. In addition, participants face an obligation to surrender the allowances owned. In this way the cap is maintained effectively.

*Figure 1.1. An example of transmission of allowances between participants.*



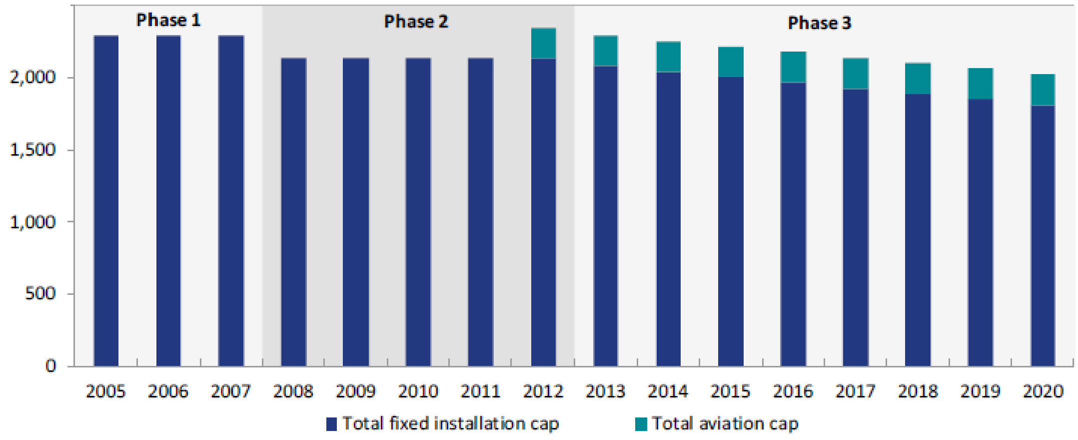

*In this picture, Factory B does not have enough allowances to cover all its emissions. It can therefore decide either to buy them from Auction Markets or to acquire them from the company A, which is in surplus of allowances. Note that factory A could also decide to bank allowances for use in later years.*

As far as the cap is concerned, it is set and established at EU level by the Commission. The single wide cap is expressed in tonnes of $CO_2$ and changes in each trading period. The cap in phase 3 ensures the meeting of the EU's 2020 greenhouse gas emissions reduction target (European Commission, 2010)[16]. As is shown in Figure 2, in the first two phases the installation cap was fixed and kept constant during the whole phase. In phase 3 things changed so that the total cap decreases each year to 2020 and beyond by a linear reduction factor. More precisely,

[16] EUROPEAN COMMISSION. (2010). Commission Decision of 9 July 2010 on the Community-wide quantity of allowances to be issued under the EU Emission Trading Scheme for 2013. (2010/384/EU). Official Journal of the European Union, 175/36. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32010D0384

it will decrease by 1.74% compared to 2010, the midpoint of the second phase. This means that in absolute terms the number of the EU Emissions Allowances (EUA) will fall annually by 38,264,246 allowances. Following this scheme, the cap for the year 2013 results to be at 2,084,301,856 EUAs.

*Figure 1.2. Single EU wide cap during the first three phases of the Emission Trading System*




*Source: the EC's webpage, https://ec.europa.eu/clima/policies/ets/cap_en*

The diagram clearly shows that from Phase 3 a decreasing cap is applied. Note that from 2013 the cap includes sectors and gases not covered in phase 2, this explains the reason why the decrease is limited. The supply of emission allowances is determined by the total number of allowances issued, either allocated for free or auctioned.  The balance between this supply and the demand of the market determines the carbon price. Scarcity is the key driven for a competitive price.

## 1.2 Main features of the EU ETS

As already stated, the Emission Trading System goes under continuous transformations. The scope of the EU ETS in terms of greenhouse gases, sectors and geography keep increasing, and this increases the effectiveness of the system as a whole. Other developments over the years are related to improvements in rules for free allocation, monitoring, reporting and verification (MRV) and to an increased use of auctioning as an allocation method, as specified in Directive

2018/410/EC[17]. From the beginning of phase 3 approximately half of the overall greenhouse gas emissions are covered by the system.

In the table 1.1, the main changes in the key features of the EU ETS during the first three phases are summarized.

*Table 1.1. Key features of the EU ETS system during the first three phases*

| Key features | Phase 1 (2005-2007) | Phase 2 (2008-2012) | Phase 3 (2013-2020) |
|---|---|---|---|
| **Geography** | EU27 | EU27 + Norway, Iceland, Liechtenstein | EU27, + Norway, Iceland, Liechtenstein, Croatia |
| **Sectors** | Power stations and other combustion plants ≥ 20MW<br>Oil refineries<br>Coke ovens<br>Iron and steel plants<br>Cement clinker<br>Glass<br>Lime<br>Bricks<br>Ceramics<br>Pulp<br>Paper and board | Same as phase 1 + Aviation (from 2012) | Same as the first two phase +<br>Aluminium<br>Petrochemicals<br>Ammonia<br>Nitric, adipic and glyoxylic acid production<br>$CO_2$ capture, transport in pipelines and geological storage. |
| **GHGs** | $CO_2$ | $CO_2$,<br>$N_2O$ emissions via opt-in | $CO_2$, $N_2O$, PFC from aluminium production |
| **Cap** | 2058 million $tCO_2$ | 1859 million $tCO_2$ | 2084 million $tCO_2$ in 2013, decreasing in a linear way every year |
| **Eligible trading units** | EUAs | EUAs, CERs, ERUs | EUAs, CERs, ERUs<br><br>Note: CERs from projects registered after 2012 must be from Least Developed Countries |

Source: The European Commission's page on the EU ETS https://ec.europa.eu/clima/policies/ets_en

[17] Directive 2018/410/EC of the European Parliament and of the Council of 14 March 2018 amending Directive 2003/87/EC to enhance cost-effective emission reductions and low-carbon investments, and Decision (EU) 2015/1814. Official Journal of the European Union, 76/3. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.076.01.0003.01.ENG&toc=OJ:L:2018:076:TOC

**Geography**

At the beginning all the 25 EU member states joined the EU ETS program. The number increased to 27 (EU27) in 2007 when Bulgaria and Romania entered the European Union. In 2008 also Liechtenstein, Iceland and Norway joined the ETS scheme which from phase 2 covered the whole European Economic Area. With the addition of Croatia in 2013 the system reached its actual extension.

**Sectors**

Starting from the most GHG-intensive sectors in the first phase, the EU ETS increased its sectoral scope in 2012 by adding the $CO_2$ emissions of the aviation sector.

In phase 3 further expansion was reached with the addition of the sectors petrochemicals and other chemicals, aluminium and carbon capture and storage.

**Greenhouse gases**

In the first phase, only $CO_2$ emissions were covered. Phase 2 allowed for voluntary inclusion of $N_2O$ emissions at the discretion of EU Member States. The EU ETS phase 3 added $N_2O$ emissions from all nitric, adipic and glyoxylic acid production and PFC emissions from aluminium production.

Besides, installations that emit less than 25 kt$CO_2$ are allowed to opt-out from the EU ETS if they are subject to similar measures because the administrative costs per unit of emissions could be relatively too high for them.

## 1.3 Benefits and results of cap and trade

The “cap and trade” structure is not the only feasible one when implementing policies about emissions reduction but it is the mechanism that better contributes in reaching the European targets in an effective way. A tax would not guarantee the achievement of the GHG emissions reduction target and, when many nations are involved, it requires agreement across all countries on the right carbon price. Determining and setting the “right price” without over- or undercharging companies is also very difficult. Another possible approach is the so-called command-and-control approach. In this case a standard limit per installation may be imposed, but at the cost of providing little flexibility to companies regarding how or where emission reductions take place. The system chosen by the EU allows to reach the emissions targets at the lowest cost through trading among companies (Laing et al. 2013)[18]. The carbon price is then set by the market, as well explained in Ellerman, Convery and De Perthuis (2010)[19].

The choice of the cap-and-trade mechanism has been driven by some important key benefits:

- Flexibility and cost-effectiveness: the system gives freedom to companies regarding how to reach the emission targets. This flexibility implies that the same carbon price is faced by each firm and ensures that cuts in GHG emissions happen where it costs least to do so.
- Certainty about quantity: the maximum quantity of GHG emissions for a period of time is known ex ante. This is reassuring for the market and well supports the EU's international objectives and environmental goals.
- Revenue: the auctioning of emission allowances results to be a source of revenue for the governments involved. At least 50% of this type of income should be used to fund measures to fight climate change in the EU.
- Minimizing risk to Member State budgets: the certainty about emission reductions reduces the risk that Member States will need to purchase additional allowances to reach their international commitments of the Kyoto Protocol.

These theoretical benefits of the EU ETS find confirmation in the results the system actually achieved during its first period of life. There is in fact a general consensus within the literature that the system has obtained greenhouse gas abatement (Healy et al. 2015)[20]. Besides, the European Commission published a statistical analysis based on data from the Community Independent Transaction Log (CITL)[21]. In their work the Commission computed the average annual emissions per installation, finding out that, for example, in 2010 average emissions decreased with respect to 2005 level more than 17.000 tonnes $CO_2$. In Table 1.2 estimates of the average abatements in emissions from various papers are reported. It can be easily noted that the literature confirms that in phase 1 an average reduction of 3% in GHG emissions has

[18] LAING T. et al. (2013). *Assessing the Effectiveness of the EU Emission Trading System*. Centre for Climate Change Economics and Policy, 126.
[19] ELLERMAN A.D., CONVERY F.J. and DE PERTHIUS C. (2010). *Pricing Carbon: the European Union Emissions Trading Scheme.* Cambridge University Press.
[20] HEALY S., SCHUMACHER K., STROIA A. and SLINGERLAND S. (2015). *Review of literature on EU ETS Performance*. Öko-Institut Working Paper 2/2015. https://www.oeko.de/oekodoc/2455/2015-001-en.pdf
[21] EUROPEAN COMMISSION. (2011). *The EU ETS is delivering emission cuts.* https://ec.europa.eu/clima/sites/clima/files/docs/factsheet_ets_emissions_en.pdf

occurred, even if abatements varied strongly across countries. However, the system is unable to deliver both GHG emissions cuts and incentive low-carbon technology. Low EUA prices in fact have failed to promote investments in such technologies and there may be the need of complimentary policies to improve the efficiency of the EU ETS.

On the other hand, adverse impacts of the emission mechanism on the economic performance of the regulated firms was not found, as explained by Martin, Muûls and Wagner (2012)[22]. Some firms were even able to increase their profits by pricing the opportunity costs of allowances obtained for free. Furthermore, there was no evidence that the EU ETS decreased the competitiveness of the regulated companies.

*Table 1.2. Estimates of abatement in the literature*

| Authors | Estimated abatement | Country | Time Period | Sector | Data source |
|---|---|---|---|---|---|
| **Ellerman and Buchner (2008)** | -2.4% to -4.7% | EU | 2005-2006 | All | NAP |
| **Ellerman, Convery and de Perthius (2010)** | -3.3% | EU | 2005-2007 | All | CRF (UNFCCC) |
| **Anderson and Di Maria (2011)** | -2.8% | EU | 2005-2007 | All | Eurostat |
| **Ellerman and Feilhauer** | -5.7% | Germany | 2005-2007 | All | CRF (UNFCCC) |

*Source: MARTIN., MUULS and WAGNER (2012). https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/48449/5725-an-evidence-review-of-the-eu-emissions-trading-sys.pdf*

[22] MARTIN R., MUÛLS M. and WAGNER U. (2012). *An evidence review of the EU Emissions Trading System, focusing on effectiveness of the system in driving industrial abatement*. Department of Energy and Climate Change. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/48449/5725-an-evidence-review-of-the-eu-emissions-trading-sys.pdf

# 2. EU ETS and the Power Sector

As we have seen in the previous chapter, the European Emission Trading System is a dynamic system in continuous transformation where deep attention is given to the way in which participants act within the mechanism and to the reaction of the market. Changes don't always influence the system as a whole but can affect only some sectors: one of the sectors in which transformations among the first three phases are more evident is the power sector.

The risk that increased costs due to climate policies could put business in international disadvantage made the Commission assign free allowances allocation in the electricity sector (among others) in the first two phases[23]. Despite the fact that allowances were received without bearing any cost, it has been found by many studies that companies in the power sector were able to pass on the cost of the allowances to costumers (Hintermann 2016, among others)[24], obtaining the so-called windfall profits. This is the reason why from the third phase, 100% of the allowances given to the power sector is subject to auctioning.

## 2.1 The risk of Carbon Leakage

Firms and sectors under the EU ETS are exposed to direct and indirect costs increases, which are summarized in the table 2.1. Direct costs are related to the need of purchasing $CO_2$ allowances; indirect costs come from the rise in the electricity price when power suppliers pass on the costs of allowances to their customers. Other indirect expenses come from administrative costs related to the compliance with carbon legislation.

The cost increase can easily lead to a loss in competitiveness when EU firms compete on foreign markets and this may induce them to transfer their production from the European Area to region characterized by a more favourable regime in terms of commitments associated to the GHG emissions. This is better known as Carbon Leakage.

[23] Brief summary of how allocation in Phase 1 and Phase 2 was determined. https://ec.europa.eu/clima/policies/ets/pre2013/nap_en#tab-0-0

[24] HINTERMANN B. (2016). *Pass-Through of $CO_2$ Emission Costs to Hourly Electricity Prices in Germany*. Journal of the Association of Environmental and Resource Economists, 3.

The Directive 2009/29/EC[25], defines Carbon Leakage as follows: "In the event that other developed countries and other major emitters of greenhouse gases do not participate in this international agreement, this could lead to an increase in greenhouse gas emissions in third countries where industry would not be subject to comparable carbon constraints (carbon leakage), and at the same time could put certain energy-intensive sectors and subsectors in the Community which are subject to international competition at an economic disadvantage. This could undermine the environmental integrity and benefit of actions by the Community".

*Table 2.1. Main costs faced by the EU ETS participants*

| EU ETS COSTS | |
|---|---|
| **Direct costs** | Come directly from the need of purchasing the Emission Allowances. EUA price is the main determinant of this type of cost. |
| **Indirect costs** | Are due to the rise in the electricity price caused by the Emission Trading System. |
| **Administrative costs** | Are related with the compliance with carbon legislation, such as back-office operations, MRV etc.. |

The risk that a company in the EU jurisdiction could be better off by relocating outside the EU area is harmful not only for its negative social effects but also from an environmental point of view. Therefore, carbon leakage may neutralize the actions taken in Europe and it is a risk that must be addressed by the European Community.

There are many ways in which this problem can be faced and the debate in Europe is not already concluded. One possible solution is the imposition of border adjustment measures for competing imports, as suggested by KUIK and HOFKES (2010)[26]. If, in fact, importers were obliged to purchase and surrender EUAs to the authorities when importing goods, the advantage of non-EU producers would be lost. This type of solution comes with some problems: first, the carbon leakage and competitiveness loss must be accurately assessed; second, the "fair" level

[25]*Directive 2009/29/EC of the European Parliament and of the Council amending Directive 2003/87/EC so as to improve and extend the greenhouse gas emission allowances trading scheme of the Community.* Official Journal of the European Union, 140/63.
https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0063:0087:en:PDF
[26] KUIK O., HOFKES M. (2010). *Border adjustment for European Emission trading: Competitiveness and carbon leakage*. Energy Policy, 38, pp. 1741-1748.

of EUAs to be imposed on imported products is not easy to estimate. For these reasons, the solutions already taken within the EU ETS concern the way in which allowances are allocated.

While in a textbook cap-and-trade system the distribution of allowances should not be relevant for the final level of activities and prices, and therefore of competitiveness, (Markusen 1975)[27], in a real-word the way in which EUAs are allocated (auction versus free allocation) may matter to the extent that sectors exposed to foreign competition could receive some relief from free allocation.

Some several provisions to limit the direct emission costs and to protect the competitive position of EU businesses are included in the EU ETS Directive (European Commission, 2015)[28] which aims to address the risk of carbon leakage. In this directive, the rules of determining sectors at risk of carbon leakage are presented. Whenever one sector meets the carbon leakage criteria, it is put in the so-called carbon leakage list, which is renewed every 5 years. These sectors received 100% of their allowances for free during the second phase, reduced to 80% from 2013 and to 30% by 2020.

The criteria to be entitled to enter the carbon leakage list are several, and consist in both quantitative and qualitative requirements. As far as the quantitative methods are concerned, a sector is "deemed to be exposed to a significant risk of carbon leakage" if:

- The sum of all additional costs (direct and indirect) subsequent to the implementation of the Emission Trading System, computed as a proportion of the Gross Value Added (GVA), would result in a substantial increase of production costs of at least 5%; and
- a non-EU trade intensity higher than 10%. The intensity can be defined as

$$\frac{total\ value\ of\ exports\ to\ nonEU + value\ of\ imports\ from\ nonEU}{total\ market\ size\ from\ the\ Community}$$

If these carbon leakage criteria are not met by a sector, there is still the possibility to enter the carbon leakage list through qualitative assessments. Sectors close to the threshold but not eligible for carbon leakage can submit the request through factors not belonging to the quantitative method. These criteria are specified in Article 10a (17) of the EU ETS Directive:

- The ability of the sector to absorb costs indicated by Profit Margins

[27] MARKUSEN J.R. (1975). *International externalities and optimal tax structures*. Journal of International Economics, 5, 15-29.

[28] EUROPEAN COMMISSION. (2015). Proposal for a directive of the European Parliament and of the Council amending Directive 2003/87/EC to enhance cost-effective emission reductions and low-carbon investments. 2015/148. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2015:0337:FIN

- The characteristics of the sector, such as the competitive position relative to non-EU producers, homogeneity of the product, the market concentration and the bargaining power of the sector
- The extent to which installations in the sector can reduce their electricity consumption or their greenhouse gas emissions through additional investments.

It must be underlined that in reality companies relocate due a wide number of factors, which include, carbon costs. Other key variables include the demand of the market, the stability of investment conditions, labour costs and overall operational costs. Many studies are investigating the degree to which carbon leakage has actually taken place, or is likely to take place, as it is shown by Marcu et al. (2013)[29]. Among more than 150 UK sectors investigated, only few showed evidences of a loss in competitiveness under the EU ETS. The manufacturing of steel, aluminium, cement and clinker resulted to be the most exposed (Hourcade et al. 2007)[30].

There is no evidence that carbon leakage has happened so far, as demonstrated by the Oko-Institut (2013)[31], and this is also due to the efforts already taken by the European Commission to address this problem. Given the limited supply of allowances the carbon cost is likely to keep on raising and hence, the situation must be kept under constant monitoring. The list of sectors affected by the carbon leakage risk is in continuous transformation and this also depends on the way in which different sectors manage the new carbon costs.

## 2.2 Cost Pass-through in the power sector

One of the main reasons of the small loss in competitiveness during the first phases of the EU ETS is that many sectors were able to pass costs related to the emission mechanism to costumers. The so-called cost pass-through defines a situation in which producers are able to increase the price of their products following an increase in producing costs. The power sector is one of the most polluting activity covered by the EU ETS and the sector that received the

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[29] MARCU A., EGENHOFER C., ROTH S. and STOEFS W. (2013). *Carbon Leakage: An Overview*. Centre for European policy Studies. CEPS Special Report 79. https://www.ceps.eu/system/files/Special%20Report%20No%2079%20Carbon%20Leakage_0.pdf

[30] HOURCADE J.C., NEUHOFF K., DEMAILLY D. and SATO M. (2007). *Differentiation and Dynamics of EU ETS Industrial Competitiveness Impacts*. Climate Strategies, Cambridge.

[31] OKO-INSTITUT AND ECOFYS. (2013). *Support to the Commission for the determination of the list sectors and subsectors deemed to be exposed to a significant risk of carbon leakage for the year 2015-2019.* https://ec.europa.eu/clima/sites/clima/files/ets/allowances/leakage/docs/carbon_leakage_list_en.pdf

largest share of the allowances in the first two phases. It is also the segment in which the cost pass-through and subsequent windfall profits are more evident (Jouvet and Solier, 2013)[32].

In literature deep attention has been given to this phenomenon, in particular Bonacina and Gulli (2007)[33] and Sijm at al. (2006)[34] put the theoretical basis of the $CO_2$ cost pass-through. The former explained it under imperfect competition, showing that the increase in electricity prices due to an increase to carbon prices is less than 100% when the market is characterized by imperfect competition; the latter determined that the pass-through level depends on many factors, such as the change in merit order due to $CO_2$ costs and the demand elasticity. According to them under perfect competition the pass-through rate should be close to 100%. Other variables that could reduce the increase in electricity price are the presence of excess capacity and a low market share of the greatest polluter.

These theoretical analyses have been followed by a great number of empirical studies that have evaluated the way in which the energy markets interact with the carbon markets during the first two phases of the EU Emission Trading System. Overall, three different approaches can be detected among the literature. The first type of analysis is characterized by the use of error-correction models which are able to enlighten long-run cointegrating relationships between carbon prices, energy and electricity (e.g. Zachmann and Hirschhausen, 2008, among others)[35]. This is also the type of analysis that we will use in our work. The second tranche of studies used the Drivers approach (e.g. Hintermann, 2010, among others)[36], showing that a relationship between energy prices and $CO_2$ prices exists and is significant. A third approach tried to estimate directly the pass-through rate of carbon costs to electricity prices. One of the most relevant work belonging to this third group is the final report made by the Energy Research Centre of the Netherlands for the European Commission (Sijm et al. 2008)[37].

The overall conclusions of these studies are that the $CO_2$ pass-through significantly occurred during the first two phases of EU ETS despite the fact that electricity producers received the allowances for free. Many factors can influence the level at which this happens:

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[32] JOUVET P. and SOLIER B. (2013). *An overview of $CO_2$ cost pass-through to electricity prices in Europe*. Energy policy, 61, pp 1370-1376.
[33] BONACINA M., GULLI F. (2007). *Electricity pricing under "carbon emissions trading": a dominant firm with competitive fringe model*. Energy Policy, 35, pp. 4200-4220.
[34] SIJM J, NEUHOFF K. and CHEN Y. (2006). *$CO_2$ cost pass-through and windfall profit in the power sector*. Earthscan, Climate Policy, 6, pp. 49-72.
[35] ZACHMAN G., HIRSCHHAUSEN C. (2008) *First evidence of asymmetric cost pass-through of EU emissions allowances: examining wholesale prices in Germany*. Economics Letters, 99, pp. 465-469.
[36] HINTERMANN B. (2010). *Allowance price drivers in the first phase of the EU ETS*. Journal of Environmental Economics and Management, 59, pp. 43-56.
[37] SIJM J., HERS S.J., LISE W. and WETZELAER B.J.H.W. (2008). *The impact of the EU ETS on electricity prices.* Final report to DG environment of the European Commissions.

- The impact of allocation on power prices. Theoretically, there shouldn't be any difference between various allocation methods. In reality free allocation may reduce the incentive to reduce $CO_2$ emissions, leading to a higher need of emissions allowances and therefore to higher electricity prices.
- The impact of market structure on power prices. This mainly depends on the shape of the demand curve (linear or not), the supply curve's shape (constant or not constant marginal costs) and the market competitiveness.
- Market strategy. The level of pass-through can also depend on whether the firms operate under profit maximization or pursuing other types of objectives, such as the maximization of sales revenues or market share.
- Market regulation. Public authorities may try to limit the scope of windfall profits or directly regulate the electricity prices.
- Market imperfections. Lack of information, risks and uncertainties may affect the level of cost pass-through.

It must be underlined that the $CO_2$ cost pass-through is perfectly rational. A producer, for instance, a power generator, can decide to use the allowances he owns either to sell them to other market participants or to cover its greenhouse gas emissions resulting from the electricity production. Hence, using an emission allowance represents the cost of not selling it and therefore it's an opportunity cost. Consequently, in line with the optimal market behaviour and the economic theory, the cost of a $CO_2$ allowance is expected to be included by the producers into their operational choices, which will result in a cost pass-through on the electricity wholesale market (whatever the way allowances are received).

The passing-through on electricity prices is indeed efficient and in line with the objectives of the EU Emission Trading System (Sijm et al. 2008)[38]. In fact, in this way:

- Consumers have the incentive to reduce their demand for carbon-generated electricity, increasing their electricity saving or switching to electricity generated by less $CO_2$ intensive sources.
- Since the cost of the allowances is not totally shifted to consumers[39], producers still have the incentive to reduce their emissions by investing in technologies with a lower emissions level, such as renewables or more efficient gas-fired plants. Besides, the shift

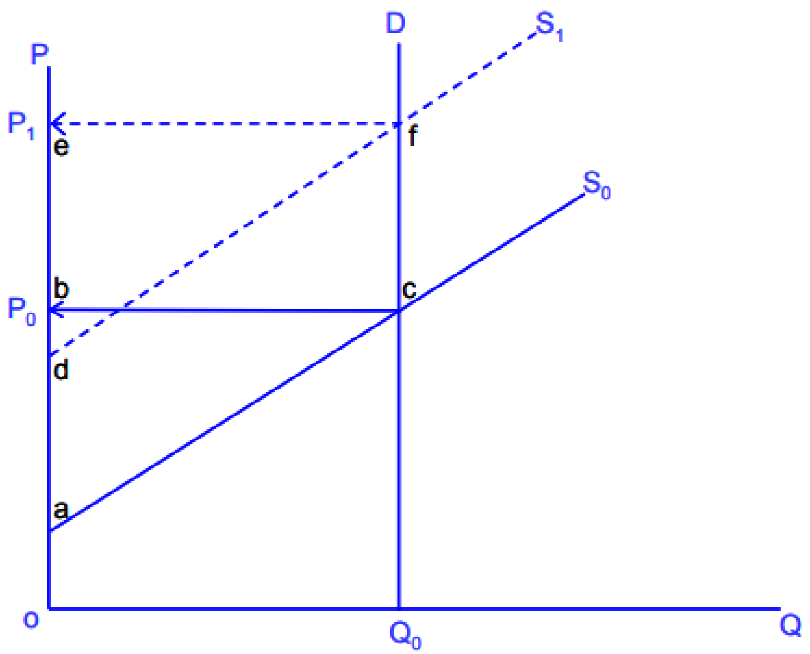
[38] SIJM J., HERS S.J., LISE W. and WETZELAER B.J.H.W. (2008). *The impact of the EU ETS on electricity prices.* Final report to DG environment of the European Commissions.
[39] SIJM et AL (2008) found that 17 out of 22 countries investigated had a pass-through level between 38% and 83% during the first phase.

in demand to less CO2 intensive generated electricity encourage producers to seek least cost abatement options.

On the contrary, if the opportunity cost of carbon allowances is not internalized into power prices, there won't be any incentive to approach low-emission options. The resulting $CO_2$ price will be higher and hence, the overall cost of the EU ETS, as shown in Radov and Klevnas (2007)[40].

While the increase in the electricity price due to the pass-through of the $CO_2$ cost is rational and intended, the same cannot be said to the windfall profits producers can achieve once they have received the allowances for free. During the first two phases of the EU ETS in fact, power producers have received most of the EUAs through free allocation, which, when combined with the cost pass-through, is more similar to receiving a lump-sum subsidy enhancing the profitability of these firms rather than actually facing a paid cost. The situation is described by the Figure 2.1.

*Figure 2.1. The pass-through of the opportunity cost of carbon allowances to power prices*




*Source: J. SIJM, S. J. HERS, W. LISE, B.J.H.W. WETZELAER. The impact of the EU ETS on electricity prices. Final report to DG environment of the European Commissions. (2008).*

[40] RADOV D., KLEVNAS P. (2007). *$CO_2$ cost pass through: German Competition Regulators' shaky economics*. Energy Regulation Insight, 31, pp. 1-7.

Figure 2.1 represents the reference case, characterized by perfect competition, a straight upward sloping supply curve ($S_0$) and an inelastic demand curve (D). It can be easily noted that the producer surplus is given by the area of the triangle abc, which corresponds to the difference between total revenues and total variable costs. After the introduction of the Emission Trading System, the opportunity costs of emission allowances are included in the production costs and the resulting supply curve shifts upward ($S_1$). As already stated, under perfect competition the pass-through level is (close to) 100%: the price in fact shifts from $P_0$ to $P_1$, and the difference is equal to the change in the marginal production costs. In the case of auctioning, there is no change in the overall producer surplus which shifts to the area of the triangle def: it can be shown in fact that the size of the triangle abc and the new triangle def is the same. The quadrangle adfc represents the total emission costs which are fully passed on to the power consumers thanks to the increase in the electricity price. This area therefore also represents the loss in the consumer surplus consequent to the cost pass-through. However, when allowances are given for free, the cost is still passed through on the electricity price and the power producers are able to increase their surplus by the area of the quadrangle adfc. This higher producer surplus due to the EU Emission Trading System is commonly known as windfall profits resulting from grandfathering.

The fact that the consumer surplus is decreased in favour of the producer one without any cost justification is a concern that has been widely addressed by policy makers, analysts and industrial stakeholders. The solution already taken by the European Commission mainly concerned the way in which emissions allowances were allocated from the third phase onwards.

## 2.3 Allocation in the power sector

The experience of the first two phases showed that the cost of the allowances was passed on the electricity prices even if EUAs were received for free. In order to address this problem, from phase 3 of the EU ETS, free allocation is no longer provided to power suppliers, who will have to buy allowances through auctioning as laid out in Article 10a(3) of the revised EU ETS Directive (2009)[41]. The power sector will be therefore subject to 100% auctioning from the third trading period onwards. Along with it, also many other industry sectors are supposed to see their free allocation level reduced from 2013. While in the first year of the third phase 80%

[41] *Directive 2009/29/EC of the European Parliament and of the Council of 23 April 2009 amending Directive 2003/87/EC so as to improve and extend the greenhouse gas emission allowance trading scheme of the Community*. Official Journal of the European Union, 140/63.
https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0063:0087:en:PDF

of the allowances will be allocated for free in the industrial sector, this value is meant to be reduced to 30% in 2020, with a view of 0% in 2027. Only sectors confirmed to be at risk of carbon leakage will continue to have 100% of the allowances received for free during the whole phase 3.

*Table 2.2. Share of free allocation calculated based on benchmarks per sector*

| | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|
| **Electricity production** | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| **Industry sectors** | 80% | 72.9% | 65.7% | 58.6% | 51.4% | 44.2% | 37.1% | 30% |
| **Industry sectors deemed exposed to carbon leakage** | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |

*Source: EUROPEAN COMMISSION, (2011), General Guidance to the allocation methodology. https://ec.europa.eu/clima/sites/clima/files/ets/allowances/docs/gd1_general_guidance_en.pdf*

From 2013, allocation criteria are determined by the new EU-wide, fully harmonised rules, as specified in the Commission Decision 2011/278/EU[42]. An allocation plan, called the National Implementation Measures (NIMs), must be prepared by the participants of the EU ETS. In this document, Member States must specify all the detailed information about the allocations planned for every installation in the country. The required data are collected by Member States, the Commission is responsible for the approval or the rejection of the NIMs instead. Therefore, while the allocation rules are EU-wide, the number of allowances allocated to each individual installation is determined by the participants themselves.

Despite the fact that the power sector is not entitled to receive any free allocation, the Directive still present some exceptions in order to support certain Member States in the modernisation of their electricity supply. It is in fact stated that, when some conditions are met, it is possible that the power sectors of these Member States can still receive a decreasing amount of free EUAs for a transitional period up to 2019. In return for transitional free allocation, these Member States must invest at least as much as the value of the allocations received in diversification of

[42] EUROPEAN COMMISSION. (2011). *Commission Decision of 27 April 2011 determining transitional Union-wide rules for harmonised free allocation of emission allowances pursuant to Article 10a od Directive 2003/87/EC of the European Parliament and of the Council.* Official Journal of the European Union, 130/1. https://publications.europa.eu/en/publication-detail/-/publication/25d79153-02b6-4370-974c-2a45baf79167

their energy mix and in the modernisation of their electricity sector. In order to receive this temporary derogation from full auctioning, Member States must meet one of the condition specified in Article 10c(1) of the EU ETS Directive 2009/29/EC[43]:

- In 2006, a single fossil fuel was responsible for more than 30% of the electricity production and the GDP per capita was not higher than 50% of the EU average; or
- In 2007, the Member State had no conjunction to the electricity grid operated by the Union for the Coordination of Transmission of Electricity (UCTE); or
- In 2007, the Member State had only one conjunction to the electricity grid operated by the UCTE with a capacity not superior than 400 MW.

Besides, temporary free allocation can be provided only to installation of power production that were operational before 2009 or for which the investment procedure was already initiated before 2009.

In order to make use of the derogation, eligible Member States must provide their chosen allocation methodology, individual allocations and a national plan about the investments in infrastructure and clean technologies to the Commission. In all other cases, the power sector is subject to 100% auctioning.

## 2.4 Auctioning in the EU ETS

Auctioning is a transparent allocation method which allows participants to acquire the emission allowances concerned at the market price. The timing, administration and other aspects of this allocation method from the phase 3 are specified in the Auctioning Regulation (No 1031/2010)[44]. According to this disposition, auctioning should be a harmonised, open, transparent and non-discriminatory process. Any auction has to be open to any potential buyer in respect of the rules of the internal market. Each country has to guarantee that their share of allowances is auctioned.

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[43] *Directive 2009/29/EC of the European Parliament and of the Council of 23 April 2009 amending Directive 2003/87/EC so as to improve and extend the greenhouse gas emission allowance trading scheme of the Community*. Official Journal of the European Union, 140/63.
https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0063:0087:en:PDF

[44] *Commission Regulation (EU) No 1031/2010 of 12 November 2010 on the timing, administration and other aspects of auctioning of greenhouse gas emission allowances pursuant to Directive 2003/87/EC of the European Parliament and of the Council establishing a scheme for greenhouse gas emission allowances trading within the Community*. Official Journal of the European Union, 302/1.
https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:302:0001:0041:EN:PDF

From the third phase, allowances can be auctioned either on a common auction platform through a joint procurement procedure or on an ‘opt-out’ auction platform. The European Commission and 25 Member States use the joint procurement approach. Poland, UK and Germany decided to opt-out instead, having their own auction platform. The main auction platforms of the EU ETS are listed in the following table.

*Table 2.3. Auction calendars*

| Auction Platform | States | Auction timing |
|---|---|---|
| **EEX** | 25 Participating Member States/ EEA EFTA States | Weekly auctions on Mondays, Tuesdays and Thursdays |
| **EEX** | Germany | Weekly auctions on Fridays |
| **ICE** | United Kingdom | Fortnightly auctions on Wednesdays |
| **EEX** | Poland | Monthly auctions on Wednesdays |

*Source: EC webpage about EU ETS Auctioning.*

*https://ec.europa.eu/clima/policies/ets/auctioning_en#tab-0-0*

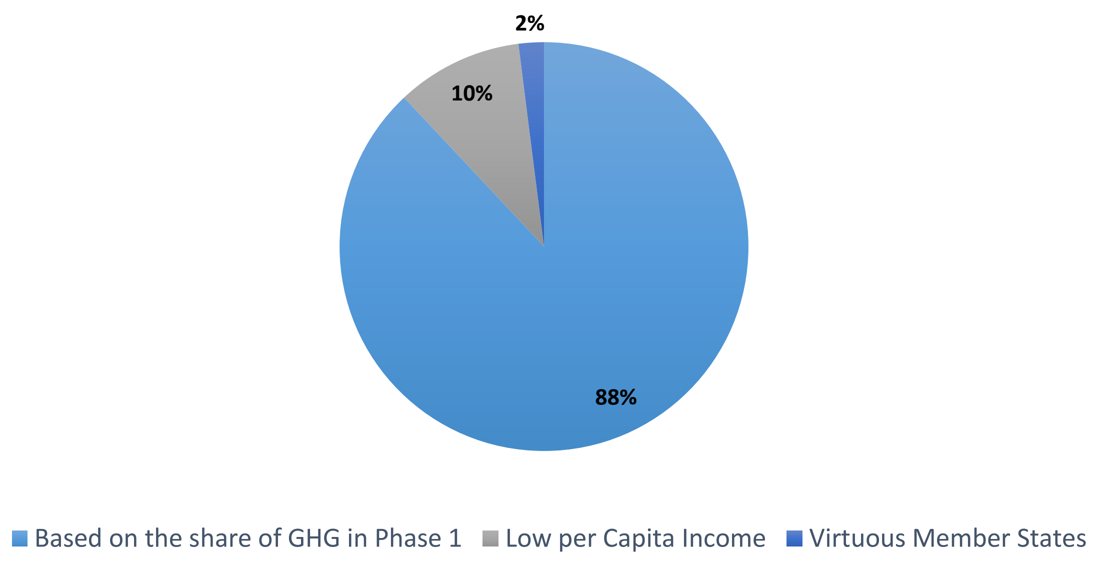
The European Energy Exchange AG (EEX) is the auction platform where 25 Member States buy and sell their allowances, and is also, separately, the opt-out common auction platform for Germany. Poland still has to list its opt-out auction platform, so it temporary uses the European Energy Exchange platform. UK uses its own auction platform, the ICE Futures Europe (ICE). Iceland, Liechtenstein and Norway also use the transitional EEX. Once the Commission has been consulted, auction calendars are fixed as soon as possible to provide certainty to the market. The auctioning of allowances on opt-out auction platforms is held separately from the common auction platform.

The article 10(2) of the EU ETS Directive (2009/29/EC)[45] specifies how auctioning rights are distributed, data are summarized in figure 2.2. First, 5% of the total quantity of allowances is stored in the New Entrant Reserve (NER); EUAs in this reserve are given for free to new entrants. In case allowances in this reserve are not allocated, they are distributed to the other

[45] Directive 2009/29/EC of the European Parliament and of the Council of 23 April 2009 amending Directive 2003/87/EC so as to improve and extend the greenhouse gas emission allowance trading scheme of the Community. Official Journal of the European Union, 140/63.
https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0063:0087:en:PDF

participants for auctioning. Member States also receive 88% of the total amount of allowances that can be auctioned. The distribution among countries is based on their share of GHG emissions in the first phase of the EU ETS. A further 10% of the auctioning rights is meant to be divided between low per capita income States. In this way, Member States with lower per capita income are able to invest in climate-friendly technologies through the additional auction revenues they receive. The remaining 2% of auction rights is given to those countries which had already achieved a reduction of at least 20% in GHG emissions by 2005, compared with the reference year set by the Kyoto Protocol. Only nine Member States were able to achieve this benefit: Slovakia, Romania, Poland, Lithuania, Latvia, Hungary, Estonia, Czech Republic and Bulgaria. If in a Member State some free allocation is provided to electricity producers according to Article 10c (2009/29/EC), the equivalent number of allowances will be deducted from the auctioning right of that participant.

*Figure 2.2. The distribution of Actioning rights, once 5% of the total quantity is set aside in the NER*




### 2.4.1 Auctioning in practice

The auction format is a single-round, sealed bid[46] and uniform-price auction. During a single bidding, any number of bids with a size of 500 or 1000 allowances can be submitted, modified or withdrew by the bidders. The number of allowances the participant would like to buy at a given price must be specified in each bid. The bidding period has to last at least 2 hours, at the

[46] A sealed-bid auction is a type of auction process in which all bidders simultaneously submit sealed bids to the platform. In this way, no bidder knows how much the others have bid. The winner of the bidding process is usually the highest bidder.

end of which the auction platform will determine and communicate the clearing price. This is the price at which the sum of volumes bid is higher or equal the volumes of allowances auctioned by Member States. A bid is successful if it's higher than the clearing price. Bid volumes are then allocated starting from the highest bid, in descending order.

Before the auction takes place, the auction platform sets a secret minimum clearing price in close consultation with the auction monitor, based on the predominant market price for EUAs before the bidding window. If the clearing price results to be below the auction reserve price, the auction is cancelled. This prevents the transmission of distortive carbon price signals. When the bidding volume is lower than the available volume for auction, the auction is also cancelled. In these cases, the auctioned volumes will be distributed over the next auctions on the same platform.

In the Auctioning Regulation the emission allowances are described as 'spot' products with a maximum delivery date of five days after the auction has taken place. Allowances are delivered one day after the auction in the EEX and ICE platforms[47]. In reality, under EU financial market legislation, these products do not belong to the 'financial instruments' category. Nevertheless, as regards customer protection, money laundering and market abuse, the protections in place are similar to those of any financial instruments covered by the European legislation, as it is ensured in the Auctioning Regulation.

As far as the auction revenues is concerned, in the Article 10(3) of the EU Directive (2009/29/EC)[48] it is established that "Member States shall determine the use of revenues generated by the auctioning of allowances". Moreover, it's also specified that at least 50% of these revenues should be used in investments that aim to combat climate change in the EU and third countries. A list of types of actions is also suggested by the Directive in the article 3d(4).

[47] EEX EU Emissions Auctions overview: https://www.eex.com/en/products/environmental-markets/emissions-auctions/overview
ICE EUA product overview: https://www.theice.com/products/197/EUA-Futures/specs

[48] Directive 2009/29/EC of the European Parliament and of the Council of 23 April 2009 amending Directive 2003/87/EC so as to improve and extend the greenhouse gas emission allowance trading scheme of the Community. Official Journal of the European Union, 140/63.
https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0063:0087:en:PDF

# 3. The Italian Power Market

In 1962 the Italian electricity sector was nationalized with the creation of ENEL, a state-controlled entity with a monopoly on production. The nationalization, which followed a tendency spreading all over Europe, was seen as the only way to efficiently supply electricity given the monopoly nature of this sector. The new company faced a rapid growth in the electricity demand during the subsequent years, which it met with fossil-fuel powered plants.

However, the 1980s were characterized by the reversed belief that more efficiency could be reached through private companies. The European Directive 96/92/EC[49], outlined the common rules for the privatization in the electricity markets. It suggests the implementation of different regulations for production and transmission: the former should be managed by private companies while the latter, being a natural monopoly, should be under the State regulation.

The European Directive was then transposed in the Italian national legislation through the legislative decree 79/1999[50]. The decree established the necessary steps for a gradual transition towards a complete liberalization of the market. A new company, Terna (the Italian TSO), became responsible for the management of the network. Moreover, a limit has been set on Enel’s property share of Terna at 20%.

In 2003, a new European Directive, 2003/54/EC[51], and a subsequent Italian decree, aimed at a free electricity trading for all commercial clients from July 2004 and, a complete opening of the market for private costumers from July 2007.

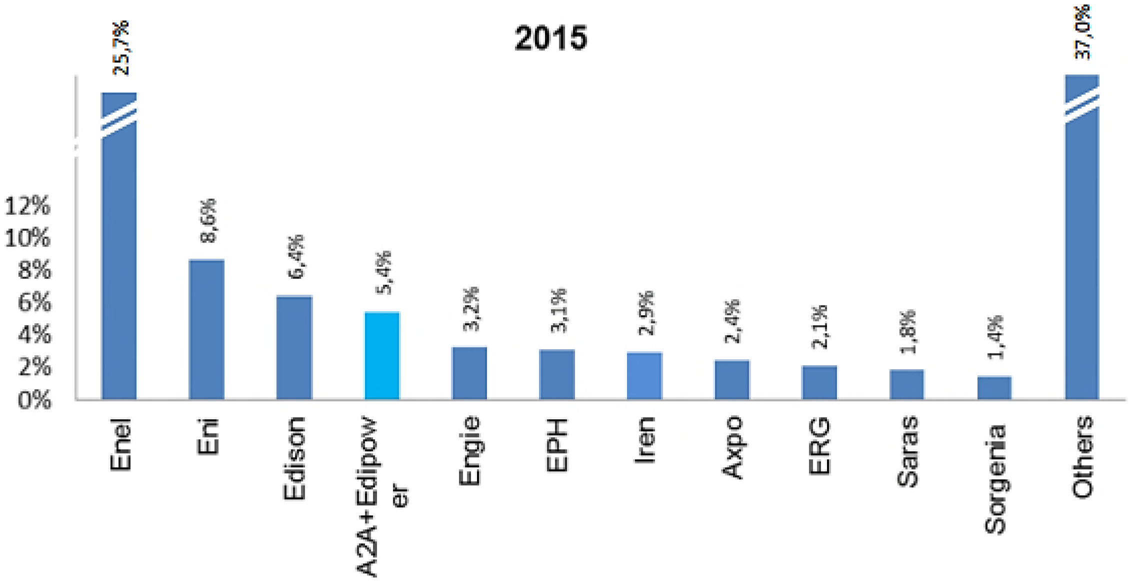
In Figure 3.1, market share of companies in the Italian power sector in 2015 are shown. It can be easily noted that the national incumbent still has the highest share. Besides, 50% of the Italian power generation is produced by the first six operators.

[49] Directive 96/92/EC of the European Parliament and of the Council of 19 December 1996 *concerning common rules for the internal market in electricity*. Official Journal of the European Union, 27. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A31996L0092

[50]Decreto legislative 16 marzo 1999, n.79, attuazione della direttiva 96/92/CE recante norme comuni *per il mercato interno dell’energia elettrica*. Gazzetta Ufficiale, 75. http://www.parlamento.it/parlam/leggi/deleghe/99079dl.htm

[51]Directive 2003/54/EC of the European Parliament and of the Council of 26 June 2003 concerning *common rules for the internal market in electricity and repealing Directive 96/92/EC – Statements made with regard to decommissioning and waste management activities*. Official Journal of the European Commission, 176. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32003L0054

*Figure 3.1 Electricity production market share in 2015*




*Source: the 2016 AEEGSI Annual Report*

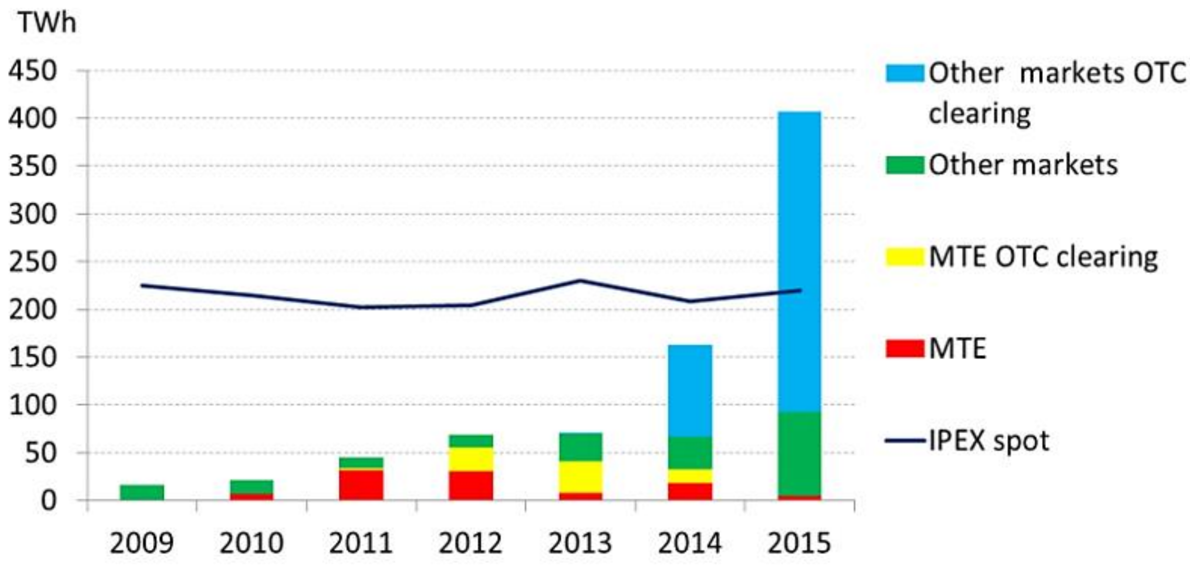
## 3.1 The Italian Power Exchange (IPEX)

In 2005, after the liberalization of the demand side bidding, the Italian wholesale electricity market begun to operate as an Exchange. Italian power, gas and environmental markets are conducted by Gestore dei Mercati Energetici S.p.A. (GME). Following the process of liberalization, GME rules the management and the economic organization of the wholesale Power Market under principles of competition, objectivity, transparency and neutrality. GME's activities are carried out under the provisions set by Autorità per Energia e Ambiente (ARERA) and under the guidelines given by the Ministry of Economic Development.

The Italian Power Exchange (IPEX) is the power market platform and it is directly managed by GME. It is the place where producers and sellers can buy and sell wholesale electricity. As far as the power is concerned, there are four sub-markets:

- MTE (mercato a termine). A forward physical market,
- MPEG (mercato dei prodotti giornalieri). A market where daily products are traded with continuous trading mode,
- MGP (mercato del giorno prima). A day-ahead auction market and
- MI (mercato infragiornaliero). An intraday auction market based on five sessions.

*Figure 3.2. Traded power volumes for Italy on forward and spot markets*




*Source: Gestore Mercati Energetici*

GME also operates a platform for the registration of OTC transactions (PCE) where contracts concluded outside the IPEX are registered. The parties involved have to record their obligations and put up the related electricity withdrawal and injection implied in the contract. As it can be noticed from Figure 3.2, in 2014 and 2015 there was a boom of volumes traded Over-the-Counter in markets different from the MTE. Besides, from 2015 the volumes traded on the Italian forward electricity market almost double those exchanged on spot markets.

Gestore dei Mercati Energetici is also a member of the Price Coupling of Regions (PCR), a European project which aims at providing technical support for the coupling of European day-ahead markets.

In 2009 GME also became the superintendent, on an exclusive basis, of natural-gas markets and associated services. The provisions are contained in Law no. 99 of the 23 July 2009[52]. The Gas Trading Platform (P-GAS) and the Wholesale Gas Market (MGAS) belong to GME's gas markets.

Besides, GME is also concerned in the implementation of environmental policies through the management and organization of environmental markets, such as the Guarantee-of-Origin (GO)

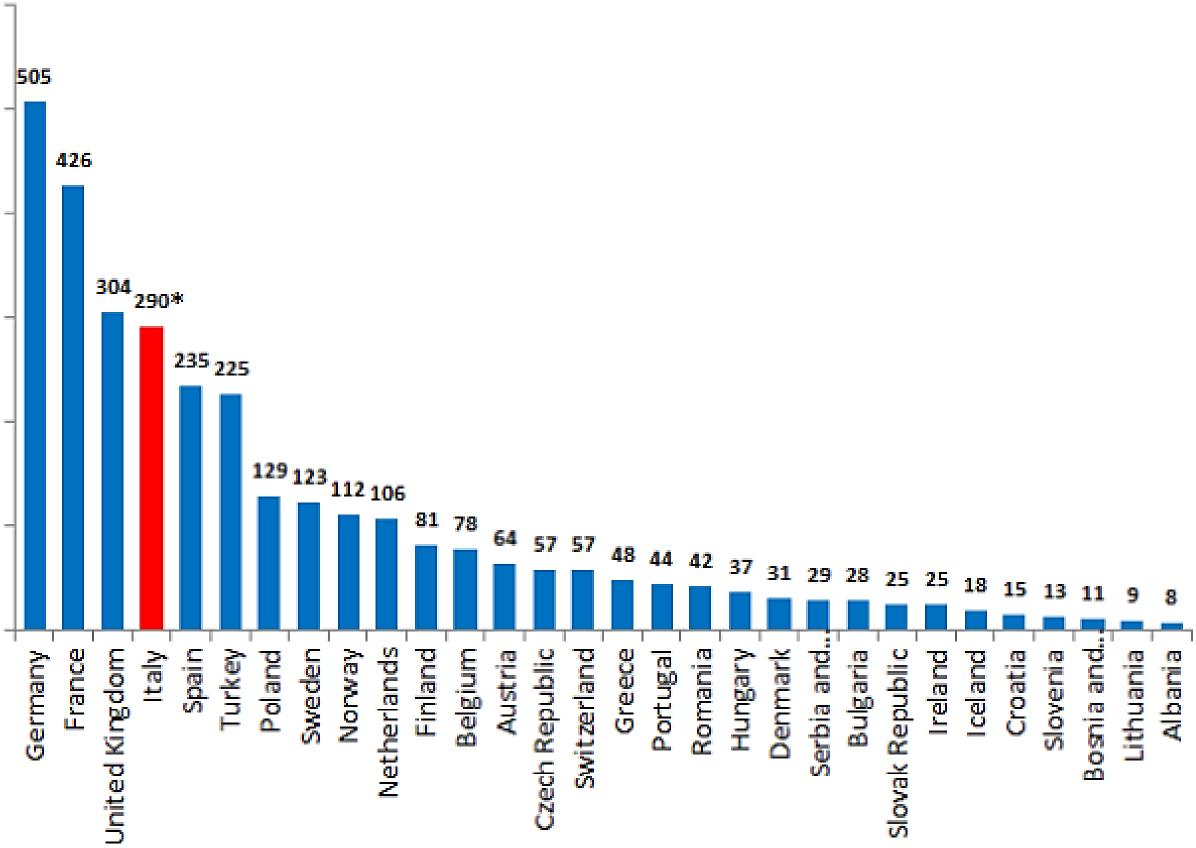
[52] Law No. 99 of July 23, 2009 containing *Provisions for the Development and Internationalization of Enterprises and Energy*. Ordinary Supplement to Official Journal, 176. https://www.oecd-nea.org/law/legislation/italy-primary-legislation.pdf

Market and the Energy Efficiency Certificates Market. Lastly, GME is responsible for the market monitoring of the Italian power Market.

## 3.2 Market overview

As far as the market size is concerned, the Italian electricity market is fourth in the European electricity market ranking, while the Italian Gas market stands third. In figure 3.3 it is shown that in 2016 the Italian power demand was about 290 TWh (almost half of the power demand of Germany, the country with the highest demand). The Italian electricity demand is mainly driven by the Industry sector (about 42% of the total), directly followed by the services sector (35%), while the agriculture sector is responsible for the smallest amount instead (2% of the total)[53].

*Figure 3.3. European Electricity Demand in 2016*



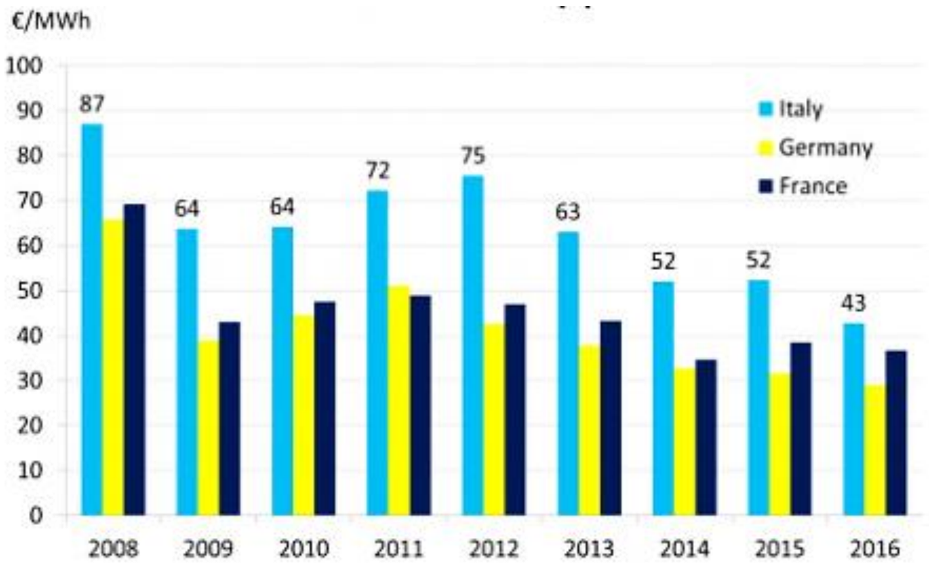

*Source: HIS Cera, Snam Rete Gas and Terna*

**Power demand data do not include losses*

53 Source: the AEEGSI 2016 annual report, Terna, Eurostat

Despite the fact that the Italian Demand is much lower than the Germany and France's ones, Italy is characterized by the highest Baseload electricity price. One of the main causes of this phenomenon is the Italian electricity production mix. While other countries strongly rely on some less-expensive sources of production, such as Nuclear Power, Italy's production is mainly based on fossil-fuel power stations and, as a consequence, the electricity price is higher.

*Figure 3.4. Baseload electricity prices*



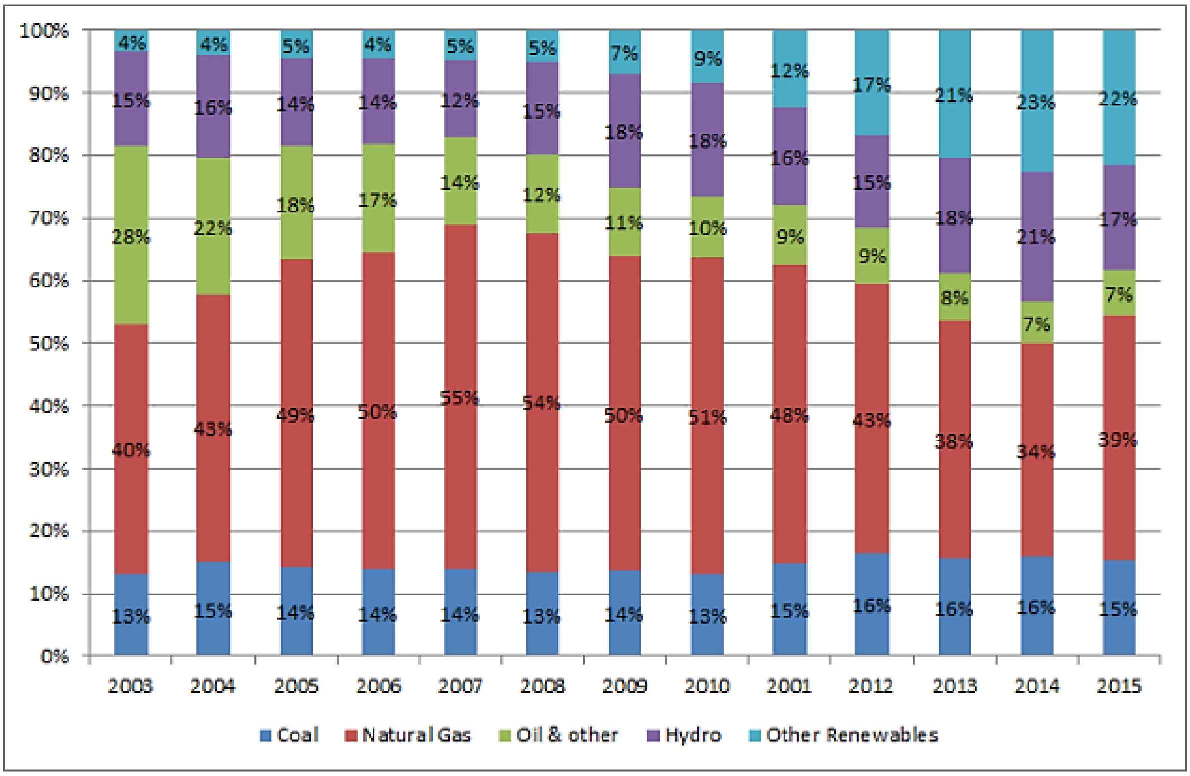

*Source: HIS Cera, Snam Rete Gas and Terna*

In fact, as can be noted from the graph, while the prices of Germany and France are close to each other, the Italian electricty price tends to be slighly higher in a consistent way. Besides, there is a trend of heavy decrease in prices since 2008 and this is probably due to generation overcapacity. Bonenti et al. (2013)[54] underline in their work that the decrease in price is also partially due to a shift to renewable sources, particullarly evident from 2013 (the year of the begginning of Phase 3 of the EU ETS). With the introduction of a 100% auctioning allocating system for the electricity market, the EU Emission Trading System incentived European countries, including Italy, to invest in power stations not based on fossil-fuel. This is the proof that the EU ETS is properly working, obtaining the results it was meant for.

[54] BONENTI F., OGGIONI G., ALLEVI A. and MARANGONI G. (2013). *Evaluating the EU ETS impacts on profits, investments and prices on the Italian electricity market*. Energy Policy, 59, pp. 242-256.

In Figure 3.5 we will report the Italian electricity production mix from 2003 to 2015. It can be easily noted that the main source of production is Natural Gas, directly followed by hydroelectric production.

*Figure 3.5. Electricity production mix*




*Source: Terna and AEEGSI annual report 2016*

The first thing the graph enlightens is the presence of a stable share of coal and hydroelectric productions. Besides, Natural Gas production is quite steady and it occupies the first place in terms of share size in the Italian production mix. Oil and renewables production fractions are characterized by opposite trends: the former decreases over time (from 28% in 2003 to 7% in 2015), the latter increases instead (from 4% in 2003 to 22% in 2015). This is the direct impact of the incentives resulting from the EU Emission Trading System. From 2014 the increase in renewables sources has slowed down due to lower incentives in the sector provided by the Italian Government. Despite this fact, in 2015, the sum of hydroelectric power and other renewables, accounts for almost 40% of the Italian total production.

More precisely, the main sources of renewable productions in 2015 are:

- 40% hydropower,
- 21% solar,
- 16% wind,
- 17% biomass,
- 6% geothermal.

According to Terna, the fall in the electricity price caused by the shift to renewable sources will be partially off-set by a slight increase in the demand which will characterize the market in the forthcoming years. The increase in demand is forecasted to go from 0.4% to 0.9% per year.

# 4. The Statistical Framework

When analysing price time series, deep attention must be given to the characteristics of the series, checking whether they meet all the criteria for a meaningful econometric analysis. Given the nature of our data, we expect them to show evidences of presence of unit roots, a problem that indeed must be addressed. For this reason, in the first part of this chapter we will explore the characteristics and qualities of the time series we are going to analyse while, in the second part, we will describe the most suitable model for our work: the Vector Error Correction Model (VECM).

## 4.1 Stationary and non-stationary processes

As mentioned by Manuca and Savit, (1996)[55], the problem of non-stationarity is one of the most challenging problems in time series analysis. Many methods that analyze time series assume that the series under investigation are characterized by stationarity. This would grant the correctness of the interpretation of the results.

Economic time series are often non-stationary instead, and, as a result, they are unpredictable and can be hardly modeled or forecasted. A non-stationary time series is a process that violates at least one of the conditions of (weak) stationarity, which are:

$$E(Y_t) = \mu \qquad (4.1)$$

$$V(Y_t) = E((y_t - \mu)^2) = \gamma_0 \qquad (4.2)$$

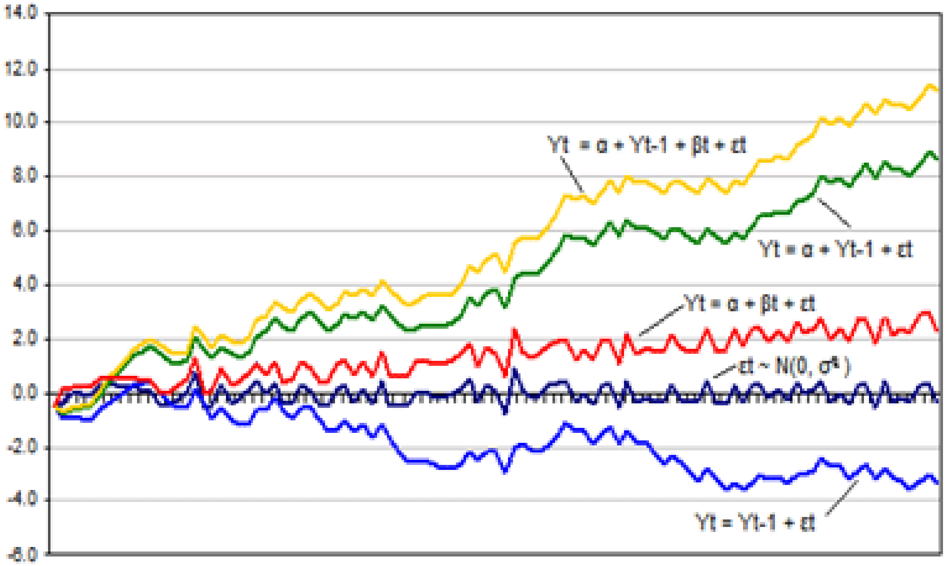
$$Cov(Y_t, Y_{t-k}) = E((y_t - \mu)(y_{t-k} - \mu) = \gamma_k \quad for\ k = 1,2.. \qquad (4.3)$$

These can be violated in different ways. Examples of non-stationary processes are reported in figure 4.1. Using non-stationary data may produce spurious results which indicate the presence of meaningful relationships when there are none. In contrast with stationary variables, non-

[55] MANUCA R. and SAVIT R. (1996). *Stationarity and nonstationarity in time series analysis*. Psysica D, 99, pp. 134-161.

stationary processes don't revert around a constant long-term mean and are characterized by a variance that changes over time.

*Figure 4.1. Examples of non-stationary processes.*




*Source: Investopedia.com*

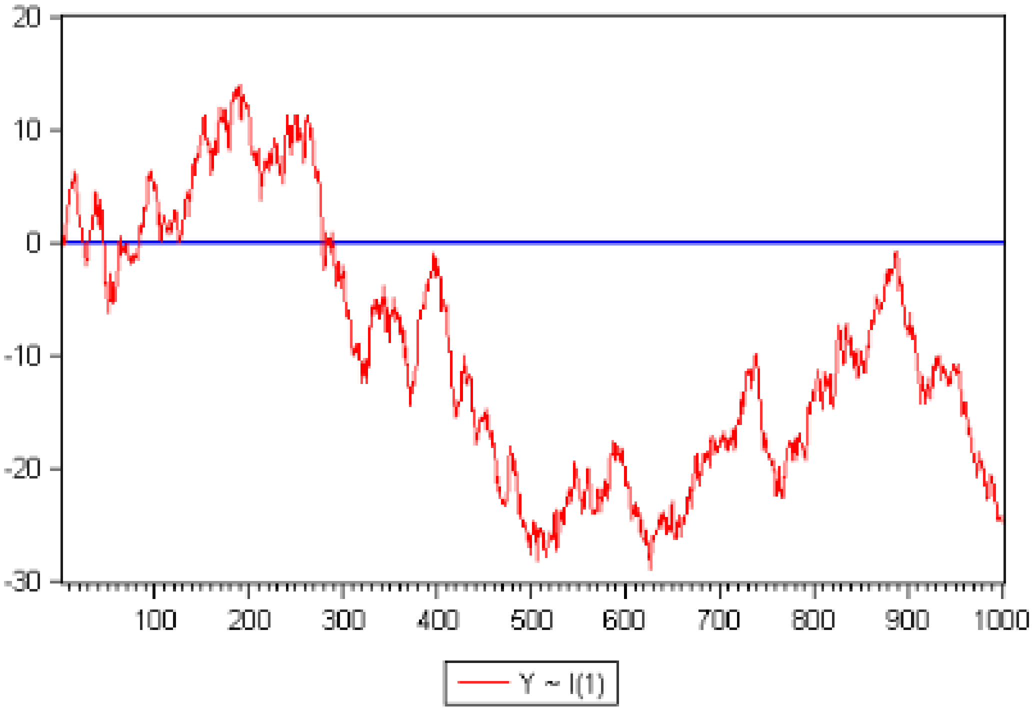
Examples of non-stationary processes are:

- **Pure Random Walk ($Y_t$=$Y_{t-1}$ + $\varepsilon_t$).** It is a non-mean reverting process that can move away from the mean either in a negative or positive direction. The variance also evolves over time, increasing as the time goes to infinity.
- **Random Walk with Drift ($Y_t$=$\alpha$+$Y_{t-1}$ + $\varepsilon_t$).** The value at time t is equal to the value of the last period plus a constant, called drift, and the white noise term. For this reason, the variance depends on time and the process doesn't revert to a long-run mean.
- **Deterministic trend ($Y_t$=$\alpha$+$\beta_t$+$\varepsilon_t$).** Differently from random walks, a non-stationary process which presents a deterministic trend has a mean that grows around a fixed trend, which is independent of time and constants.
- **Random walk with Drift and Deterministic Trend ($Y_t$=$\alpha$+$Y_{t-1}$ + $\beta_t$ + $\varepsilon_t$).** This process specifies that the value at time t is given by the stochastic component, the trend, a drift and the last period's value.

This latter process is also better known as a unit-root process. If a time series is characterized by unit roots, it shows a systematic pattern that is unpredictable (Granger and Swanson, 1997)[56]. This indeed causes a problem of non-stationarity which, however, can be solved through a series of successive differences d, with which the time series is transformed into a stationary process.

Non-stationary processes that can be converted in this way are called series integrated of order k. Economic time series are usually of the order of integration of 0 or 1; it's rare to see higher orders of integration.

*Figure 4.2. An example of I(1) process.*




An I(0) time series is therefore a non-integrated (stationary) process. Davidson (2009)[57], states that it is possible to define an I(0) process as a specific condition that make the asymptotic theory valid. Analytically, a stochastic process is said to be integrated of order 0 or I(0) if

$$y_t = \sum_{j=0}^{\infty} \Psi_j \varepsilon_{t-j} = \Psi(L)\varepsilon_t \qquad \text{is s.t. } \Psi(1) \neq 0 \tag{4.4}$$

[56] GRANGER C.W.J and SWANSON N.R. (1997). *An introduction to stochastic unit-root processes*. Journal of Econometrics, 80, pp. 35-62.
[57] DAVIDSON J. (2009). *When is a Time Series I(0)?* In The Methodology and Practice of Econometrics. Oxford University Press, available at http://people.exeter.ac.uk/jehd201/WhenisI0.pdf

A stochastic process is said to be integrated of order d or I(d) if $x_t$

$$(1-L)^d y_t = \Delta^d y_t = x_t \quad \text{is s.t.} \quad x_t \sim I(0) \tag{4.5}$$

The presence of a unit root does not automatically imply that the series is I(1), a further requirement is that the series in difference is I(0). As specified by Phillips (1952)[58], linear regression between I(1) series usually don't have much sense, that's the reason why they are called spurious regressions. But when the series show a common trend, it's possible that even if they are I(1), their linear combination is stationary. This is the so-called cointegration, firstly introduced by Engle and Granger (1987)[59].

## 4.2 Cointegration

As already stated, regressions based on non-stationary processes can lead to spurious results. This can be noted from values close to zero of the DW and $R^2$ statistics. But, if there exists a stationary linear combination of the nonstationary processes the problem can be solved; in this case, the variables combined are said to be cointegrated.

**Definition**. A vector of k time series $y_t$ with $y_t \sim I(1)$, i = 1,2, …, k, is said to be cointegrated if exists a vector β with k dimension such that

$$\beta' y_t = \beta_1 y_{1,t} + \beta_2 y_{2,t} \dots + \beta_k y_{k,t} \sim I(0) \tag{4.6}$$

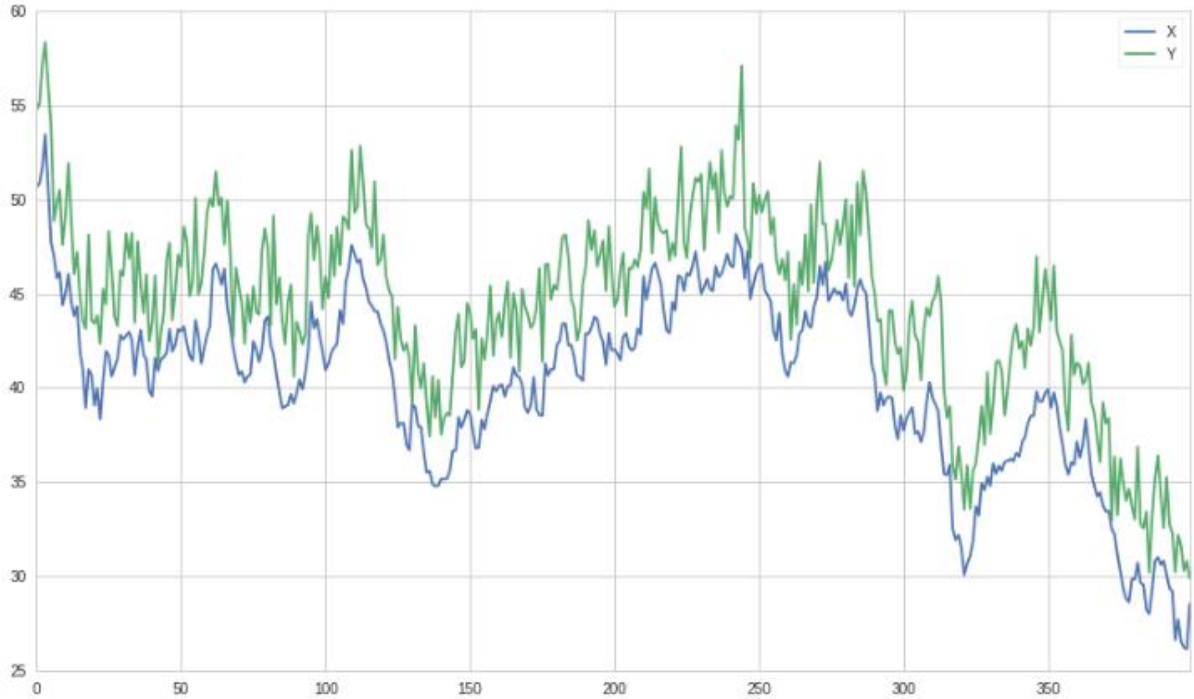
If the linear combination of the elements of $y_t$ with weights equal to β is integrated of order 0 we are in presence of cointegration, indicated as $y_t \sim CI(1,1)$. Even if the definition can be generalized, the case CI(1,1) is sufficient for our analysis.

The vector β is called vector of cointegration while the relationship $\beta' y_t$ is called cointegrating relationship or regression. The economic theory usually suggests useful rationales for finding relationships of cointegration. I(1) time series with a long-run equilibrium relationship cannot drift too far apart from the equilibrium because economic forces will operate to restore the

[58] PHILLIPS P.C.B. (1986). *Understanding Spurious Regressions in Econometrics*. Journal of Econometrics, 33, pp: 311-340.
[59] ENGLE R.F. and GRANGER W.J. (1987). *Co-integration and error correction: Representation, estimation and testing*. Econometrica. 55: pp. 251–276.

equilibrium relationship. For example, money supply and price level are typically integrated of order one while their difference should be stationary in the long run as, according to economic principles, money supply and price level cannot diverge in the long-run. Besides, a graphical representation of the time series can provide evidences of cointegration. In Figure 4.3 an example of two cointegrating processes is showed.

*Figure 4.3. An example of two cointegrated time series, X and Y.*




*Source: https://www.researchgate.net/figure/Two-cointegrated-time-series_fig1_317598743*

The cointegration vector β is not unique since for any scalar c, the linear combination $c\beta' Y_t = \beta^{*\prime} Y_t \sim I(0)$. Hence, some normalization assumption is needed to uniquely identify the parameter β. The most common normalization is

$$\beta = (1, \beta_2, \beta_3, .., \beta_k)' \qquad (4.7)$$

So that we can express the cointegrating relationship as

$$\beta' y_t = y_{1,t} - \beta_2 y_{2,t} - \beta_3 y_{3,t}, \dots, -\beta_k y_{k,t} \sim I(0) \tag{4.8}$$

$$y_{1,t} = \beta_2 y_{2,t} + \cdots + \beta_n y_{n,t} + u_t \qquad where\ u_t \sim I(0) \tag{4.9}$$

Generally, with k component in $y_t$ there can be 0 < r < k cointegrating relationships. Given the vector of k dimension $y_t$, with a rank of cointegration r, the k series share (k-r) common trend.

## 4.3 The Vector Error Correction Model (VECM)

Engle and Granger (1987)[60] showed that cointegration implies the presence of the so-called Error Correction Model (ECM). For example, in a bivariate case of cointegrated vectors, the model can be written in the form

$$\Delta y_{1,t} = c_1 + \alpha_1 (y_{1,t-1} - \beta_2 y_{2,t-1}) + \sum_j \varphi_{11}^j \Delta y_{1,t-j} + \sum_j \varphi_{12}^j \Delta y_{2,t-j} + \varepsilon_{1t} \tag{4.10}$$

$$\Delta y_{2,t} = c_2 + \alpha_2 (y_{1,t-1} - \beta_2 y_{2,t-1}) + \sum_j \varphi_{21}^j \Delta y_{1,t-j} + \sum_j \varphi_{22}^j \Delta y_{2,t-j} + \varepsilon_{2t} \tag{4.11}$$

These equations describe the dynamic behavior of $y_{1t}$ and $y_{2t}$. The ECM has the great property of linking the long-run equilibrium relationship which derives from the cointegration with the short-run dynamic adjustment mechanism that show how the variables respond when they move out of the long-run equilibrium. This is the reason why the Error Correction Model is particularly useful in modelling financial time series.

The author of the model also developed a simple two-step residual-based testing procedure for identifying presence of cointegration when there is at most one cointegrating vector. Limits of this procedure come from the fact that it considers only one cointegrating vector, for this reason, in our work, we used the method developed by Johansen (1988)[61]. With the Johansen's technique $0 \leq r < n$ cointegrating vectors are possible and the cointegrating relationship is

[60] ENGLE R.F. and GRANGER W.J. (1987). *Co-integration and error correction: Representation, estimation and testing*. Econometrica. 55: pp. 251–276.
[61] JOHANSEN S. (1988). *Statistical Analysis of Cointegration Vectors*. Journal of Economic Dynamics and Control, 12, pp. 231-254.

identified through a sophisticated sequential procedure. Besides, Johansen has the merit of having linked cointegration and error correction models in a vector autoregression framework.

If we consider a vector of I(1) variables $Y_t$, we can say that the vector is cointegrated if there is a linear combination of the variables in Yt which is I(0). In this case, a VAR representation is no more the most appropriate for the analysis because the cointegration relationships are not explicit. If the set of variables is found to have one or more cointegrating vectors, then a useful representation is the so-called Vector Error Correction Model (VECM), developed by Johansen (1955)[62], which adjust to both short and run changes in variables and deviations from the equilibrium.

$$\Delta y_t = \Pi y_{t-1} + \sum_{j=1}^{p-1} \mathbb{\Gamma}_j \Delta y_{t-j} + \varepsilon_t \tag{4.12}$$

Where

$$\Pi = \phi_1 + \phi_2 + \cdots \phi_p - I_k = -\phi(1) \tag{4.13}$$

$$\mathbb{\Gamma}_j = -(\phi_{j+1} + \phi_{j+2} + \cdots + \phi_p), \;\; j = 1,2,\dots,p-1 \tag{4.14}$$

Hence, the VECM representation contains both I(1) terms, $Y_{t-1}$, and both I(0) terms, which correspond to $\Delta y_t$ and its lags. Consequently, it is necessary that $\Pi y_{t-1} \sim I(1)$ to have $\Delta y_t \sim I(0)$. This is only possible if the cointegration relationship is contained in $\Pi y_{t-1}$.

Recalling that r is the number of cointegration relationships and k is the number of variables in the vector $Y_t$, we can distinguish three cases:

- **rank($\boldsymbol{\Pi}$) $= \boldsymbol{k}$**. There is no cointegration since the time series are not integrated.
- **rank($\boldsymbol{\Pi}$) $= \mathbf{0}$**. The VECM form is reduced to a VAR model in difference. The starting time series are integrated but there is not cointegration among them. A model in difference is sufficient for the analysis.

[62] JOHANSEN S. (1955). *Likelihood-Based inference in Cointegrated Vector Autoregressive Models*. Oxford University Press.

- **0 < rank(*Π*) < k**. This is the most interesting case where $y_t \sim I(1)$ and r vectors of cointegration exist. Therefore there are r linear combination of $y_t$ that are I(0).

If rank(*Π*) = r < k, the matrix rank *Π* can be factorized

$$\Pi = \alpha\beta' \tag{4.15}$$

Where α and β are k x r matrixes with rank r. In this case, the VECM representation becomes

$$\Delta y_t = \alpha\beta' y_{t-1} + \sum_{j=1}^{p-1} \Gamma_j \Delta y_{t-j} + \varepsilon_t \tag{4.16}$$

where $\beta' y_{t-1} \sim I(0)$ and the matrix β contains the r vectors of cointegration. α is the matrix of the adjustment factors, which indicate the adjustment speed towards the equilibrium. To identify exactly the parameters α and β, normalizations and restrictions are needed.

As we already mentioned, there are several different frameworks for estimation and inference in cointegrating system. In this paper we will mainly use methods based on the maximum likelihood (ML) methods developed by Johansen. His procedure can be summarized in the following steps:

- Estimate a VAR model of order p for $Y_t$,
- Obtain and evaluate the rank of the matrix *Π* to identify the number of cointegrating relationships r,
- Decide which normalization restrictions to impose (if necessary) on the cointegration vectors,
- Estimate the VECM.

Johansen developed a test, called the Johansen test of cointegration, that allows to easily identify the rank of the matrix and obtain the number of cointegrating relationship. Besides, he showed in his work the properties of the estimators of the model:

- The β estimator is super-consistent

- The β estimator has a non-standard distribution equal to a mixture of normal distributions
- The properties of the β estimator allow inference on the parameters included in β through usual tests which have a $\chi^2$ asymptotic distribution
- Also $\hat{\alpha}(\beta)$ has an asymptotic distribution and therefore standard inference is feasible.

The model can be generalized allowing for a linear trend and a constant. Equation (4.16) therefore becomes

$$\Delta y_t = \alpha\beta' y_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta y_{t-i} + v + \delta t + \varepsilon_t \tag{4.17}$$

Where δ is a K x 1 vector of parameters. Since this model is based on the differences of the variables, the constant implies a linear time trend in the levels, while the time trend δt implies a quadratic time trend in the levels of the data. Often, we may want to include a constant or a linear time trend in the differences without allowing for the higher-order trend that is implied in levels. VECMs exploit the properties of the matrix α to achieve this flexibility.

For this purpose, the deterministic components can be redefined as

$$v = \alpha\mu + \gamma \tag{4.18}$$

$$\delta t = \alpha\rho t + \tau t \tag{4.19}$$

In this way, the model becomes

$$\Delta y_t = \alpha(\beta' y_{t-1} + \mu + \rho t) + \sum_{i=1}^{p-1} \Gamma_i \Delta y_{t-i} + \gamma + \tau t + \varepsilon_t \tag{4.20}$$

Placing restriction on the trend terms of this equation allow us to obtain five distinct cases:

CASE 1: No constant, $\tau = 0$, $\rho = 0$, $\gamma = 0$ and $\mu = 0$

This specification assumes that there are no nonzero means or trend. It also assumes that the cointegrating equations are stationary with zero mean and that the differences and the levels of the data have zero mean. This case is unlikely to occur with economic time series.

CASE 2: Restricted constant, $\tau = 0$, $\rho = 0$ and $\gamma = 0$

With these restrictions, we assume that there are no linear time trends in the levels of the data. This specification allows the cointegration equations to be stationary around a constant mean, but it allows no other trends or constant terms. As we will show below, this is the case of interest in our study.

CASE 3: Unrestricted constant, $\tau = 0$ and $\rho = 0$

In this way, we exclude the possibility that the levels of the data have quadratic trends, and we restrict the cointegrating equations to be stationary around a constant mean. Since $\gamma$ is not restricted to 0, this specification still puts a linear time trend in the levels.

CASE 4: Restricted trend, $\tau = 0$

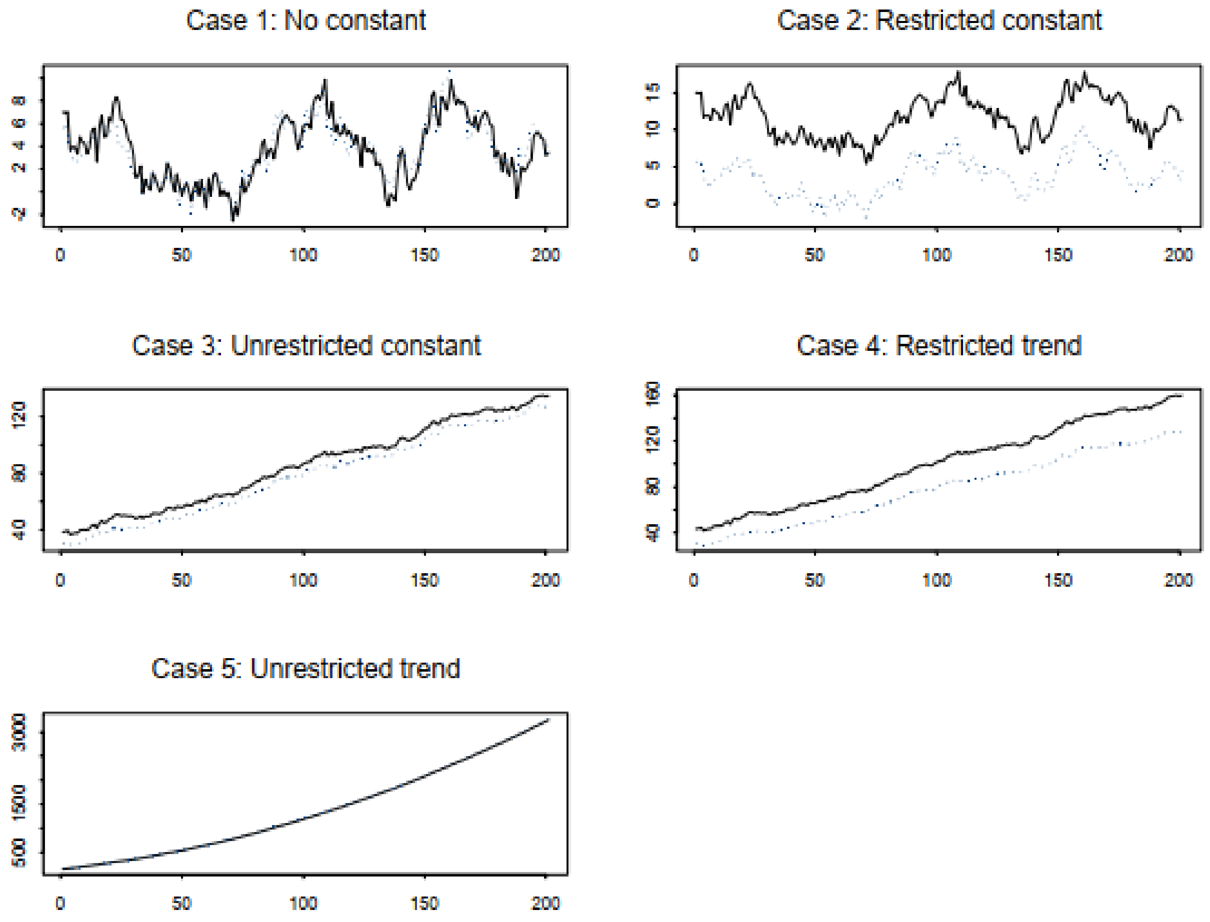
By setting $\tau = 0$, we are assuming that the trends in the levels are linear (around a constant) but not quadratic. This specification allows the cointegrating equations to be trend stationary.

CASE 5: Unrestricted constant and trend

If no restrictions are placed on the trend parameters, (4.20) implies that there are quadratic trends in levels of the variables and that the cointegrating equations are stationary around a time trend.

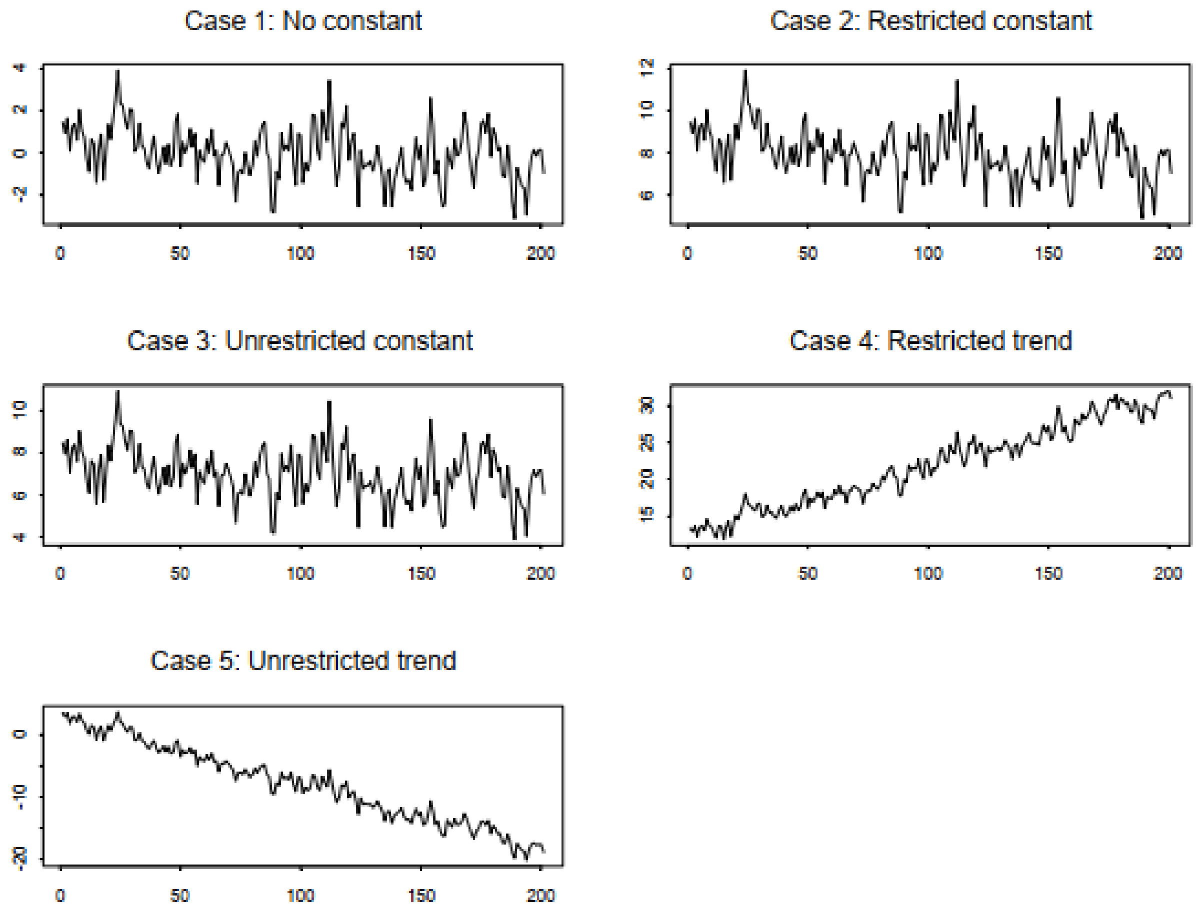
In the following figures, a graphical representation of these cases is showed.

*Figure 4.4. Simulated Yt from bivariate cointegrated VECM for five trend cases*




*Source: https://faculty.washington.edu/ezivot/econ584/notes/cointegration.pdf*

*Figure 4.5. Simulated β'Yt from bivariate cointegrated VECM for five trend cases*




*Source: https://faculty.washington.edu/ezivot/econ584/notes/cointegration.pdf*

# 5. The Empirical Analysis

Our study examines the pass-through of $CO_2$ cost on the Italian Electricity price. In the first two phases of the EU Emission Trading System, power producers passed the cost of the emission allowances on the electricity price, even if EUAs were received for free. For this reason, in the third phase, 100% of the allocation to the power market is subject to auctioning. In this dissertation we aim at assessing the new pass-through level in the Phase 3 and the magnitude of this phenomenon in the Italian market which has one of the highest final electricity price in Europe.

After a brief description of the data, we will conduct some analysis on our time series, in particular checking whether they present unit roots and are therefore non-stationary. This will allow us to decide which type of model fits best our work: if no evidence of non-stationarity is found, a VAR model is sufficient; if, however, our processes prove to be non-stationary, cointegration models must be considered.

**5.1 Data**

As we wish to measure the effect of a change in the price of the allowances to the Italian electricity price, these two are the first two series of data we need. We also decided to add the Natural Gas price to our model, as a control variable, since it is the main source used in the electricity production. Our model will therefore analyse the interconnections between three different time series from 2012 to the end of 2017.

As a proxy for the wholesale power price in Italy, we considered the PUN (Prezzo Unico Nazionale), which is traded in the MGP, the Italian Day-Ahead Market. In the MGP the power selling price differs according on the zone, the purchase offers are valued at a single national price instead: the PUN, which is simply an average of the zonal prices, weighted to the total purchases. The price is determined by the match of supply and demand and it’s hourly, for this reason we transformed it into a daily price through a weighted average with the total volumes exchanged. In fact, all prices in our study are settlement prices observed with daily frequency, from Monday to Friday. Data are retrieved directly from the GME’s webpage[63], since they are public for the sake of transparency and objectivity.

[63] http://www.mercatoelettrico.org/It/Default.aspx

EUA futures prices are obtained from the European Climate Exchange (EEX), the most liquid platform for this type of products[64]. EEX futures contracts, in €/ton, have been traded since April 2005 and have physical settlement. The underlying instrument is represented by EUAs, and each contract represents 1,000 emission allowances. The methodology for the establishment of daily settlement prices on the EEX contracts is described directly in the exchange's webpage[65]. Data were then practically obtained from the Thomson Reuters Eikon DataStream.

In additional to the EUAs prices, our dataset includes Italian PSV (Punto di Scambio Virtuale) natural gas future prices, from the ICE Exchange. Contracts are for delivery or purchase through the transfer of rights in respect of natural gas at the Punto di Scambio Virtuale (Virtual Trading Point – PSV) organized and managed by Snam Rete Gas. All the detailed information is available at the exchange's webpage[66]. Data were then practically obtained from the Thomson Reuters Eikon DataStream.

Table 5.1 provides summary statistics of all the variables.

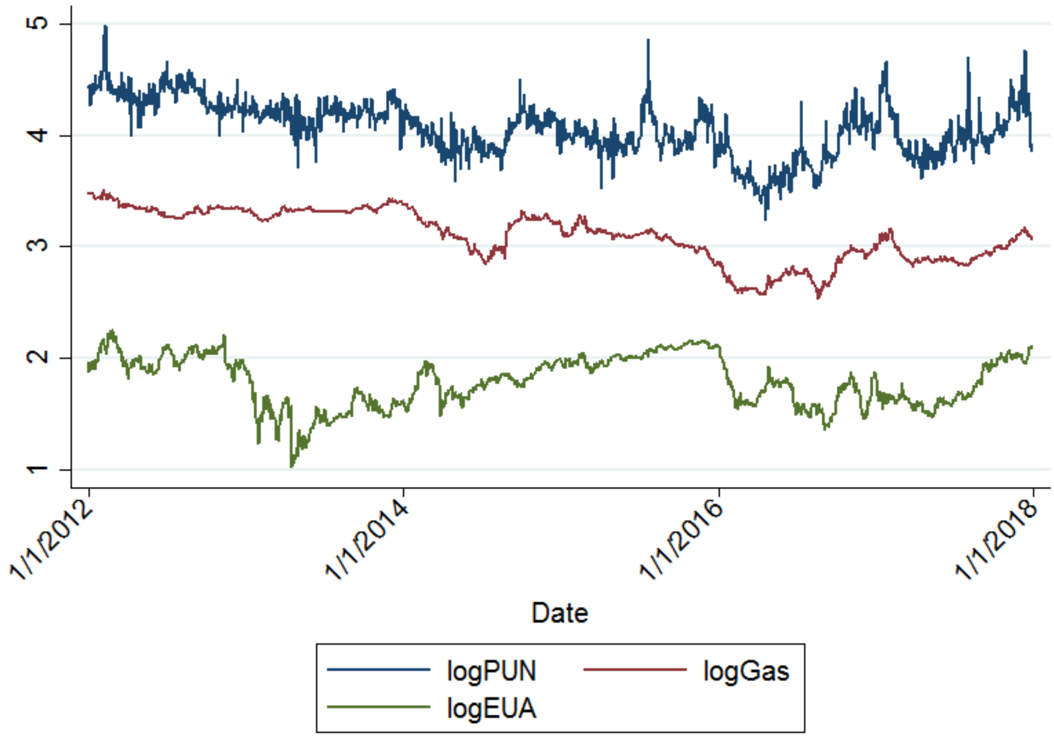
*Table 5.1. Summary statistics*

| **Variable** | **Sample Period** | **Unit** | **Obs** | **Mean** | **Std.Dev** | **Skewness** | **Kurthosis** |
|---|---|---|---|---|---|---|---|
| **PUN** | 01/01/2012-31/12/2017 | €/MWh | 1565 | 60.3191 | 15.0848 | 0.7207 | 4.4965 |
| **Gas** | 01/01/2012-31/12/2017 | €/MWh | 1565 | 22.8079 | 4.9195 | -0.1612 | 1.9227 |
| **EUA** | 01/01/2012-31/12/2017 | €/ton | 1565 | 6.1578 | 1.3668 | 0.0565 | 1.9833 |

For our purpose, also a graphical representation of the data is useful. Traces of non-stationarity can in fact be detected in this way. All variables have been transformed into natural logarithms.

[64] Approximately 96% of the volume of futures contracts is traded on this exchange. CHEVALLIER J. (2010). *Modelling risk premia in $CO_2$ allowances spot and futures prices*. Economic Modelling, 27, pp. 717-729.
[65] https://www.eex.com/en/products/environmental-markets/emissions-auctions/archive
[66] https://www.theice.com/products/49321531/Italian-PSV-Natural-Gas-Futures

*Figure 5.1. Graphical representation of our time series.*




The three variables of our model seem to be correlated and potentially I(1) processes. We will therefore investigate the presence of unit roots and of cointegrating relationships.

## 5.2 Methodology

As underlined by many authors, Lo Prete and Norman (2013) among others[67], energy prices are typically non-stationary variables: misleading values of $R^2$, Durbin–Watson and $t$ statistics can be obtained from the Ordinary Least Squares (OLS). The standard inference is not valid and this may lead the researcher to find meaningful relationships when in reality there is none. One possible solution to this problem is differencing the time series one or more times. This would resolve the invalidity of the OLS but at the same time information on the long-run relationship could be lost.

That's why we decided to apply the Vector Error Correction Model, previously described, which has the great merit of adjusting to both short and run changes in variables and deviations from the equilibrium. As we already mentioned in Chapter 4, we will use the method developed

[67] LO PRETE C., NORMAN C.S. (2013). *Rockets and feathers in power future markets? Evidence from the second phase of the EU ETS*. Energy Economics, 36, pp. 312-321.

by Johansen based on the maximum likelihood (ML). Remember that this procedure can be summarized in the following steps:

- Estimate a VAR model of order p for $Y_t$,
- Obtain and evaluate the rank of the matrix $\Pi$ to identify the number of cointegrating relationships r,
- Decide which normalization restrictions to impose (if necessary) on the cointegration vectors,
- Estimate the VECM.

Before applying the methodology proposed, we firstly want to check if the time series are actually I(1) processes, as we expect. This can be done generally checking the graphical representation of the data and through the implementation of the so-called unit root tests. In this work we used the GLS Dickey-Fuller (DF-GLS) test[68], the Augmented Dickey-Fuller (ADF) test[69], the Phillips-Perron (PP) test[70] and the Kwiatkowski–Phillips–Schmidt–Shin (KPSS) test[71]. In fact, since these tests are known for having low statistical power, the application of more than one test is strongly suggested. The null hypothesis is generally defined as the presence of a unit root and the alternative hypothesis is either stationarity, trend stationarity or explosive root depending on the test used. The KPSS test has a null hypothesis of trend stationarity rather than the presence of a unit root.

The literature specify that some tests have more power than others, for example the DF-GLS test proposed by Elliott is similar to the ADF test but firstly transforms the actual series via generalized least-squares (GLS) regression.

In order to check the consistency of the results of the unit root tests, we performed every mentioned test on each variable. For the sake of synthesis, we will report in the table 5.2 only the result of the KPSS test, while all the other values can be found in the appendix[72]. The optimal lag selection has been chosen through the Akaike Information Criterion (AIC). Using other types of information criteria did not influence the results of the tests.

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[68] ELLIOT G.R., ROTHENBERG T.J., and STOCK J.H. (1996). *Efficient tests for an autoregressive unit root*. Econometrica, 64: pp. 813–836.
[69] DICKEY D.A. and FULLER W.A. (1979). *Distribution of the estimators for autoregressive time series with a unit root*. Journal of the American Statistical Association, 74, pp. 427–431.
[70] PHILLIPS P.C.B., and PERRON P. (1988). *Testing for a unit root in time series regression*. Biometrika, 75, pp. 335–346.
[71] KWIATKOWSKI D., PHILLIPS P.C.B., SCHMIDT P., and SHIN Y. (1992). *Testing the null hypothesis of stationarity against the alternative of a unit root: How sure are we that economic time series have a unit root?* Journal of Econometrics, 54, pp. 159–178
[72] Appendix A. The unit root tests

*Table 5.2. KPSS test*

| VARIABLE | LAG | TEST STATISTIC | REJECT H0 |
|---|---|---|---|
| **LOGPUN** | 3 | 14.7 | Yes |
| **LOGEUA** | 2 | 2.88 | Yes |
| **LOGGAS** | 3 | 27 | yes |

*In all cases the test has been run around a constant with no trend. The rejection refers to the rejection of the null hypothesis of stationarity at a 10% confidence level.*

All the three variables reject the null hypothesis of stationarity at a 10% confidence level. The consistency of this result is supported by the other unit root test, whose values can be found in the appendix[73]. This suggests that the time series considered could be integrated process of order one. For completeness, we therefore decided to check whether the variables in first difference don't show any evidence of presence of unit roots. For this purpose, we applied the Augmented Dickey-Fuller test on the differenced series. In table 5.3, the results of this test are reported.

*Table 5.3. Unit root test on the differenced variables*

| VARIABLE | LAG | TEST STATISTIC | ACCEPT H0 |
|---|---|---|---|
| **D.LOGPUN** | 2 | -33.463 | No |
| **D.LOGEUA** | 2 | -25.263 | No |
| **D.LOGGAS** | 3 | -19.920 | No |

*In all cases the test has been run without the trend option and the lag length follows the AIC. In the ADF test the H0 refers to the presence of a unit root with a 10% confidence level.*

[73] Appendix A

As it is shown in the table, with all the three variables we reject the null hypothesis of presence of a unit root in favor of the alternative. The processes therefore are stationary in first difference.

We are now able to apply the Johansen procedure, seeking for cointegrating relationships among the variables. More precisely, we will apply the Johansen test of cointegration (Johansen 1991)[74], which, through the estimation of the rank of the matrix assesses the number of cointegrating relationships. This test is more generally applicable than the Engle-Granger test because it permits more than one relationship of cointegration.

In this test, there are two possible test statistics, the trace statistic or the maximum eigenvalue statistic. In the case of the trace statistic, the test is built as follows:

$$H0: r = r* < k$$

$$H1: r > r*$$

and it works sequentially testing for $r* = 0,1,2..etc.$ The testing procedure begins checking the zero cointegrating equations case (a maximum rank of zero) and then accepts the first null hypothesis that we fail to reject.

The null hypothesis of the maximum eigenvalue statistic is the same as in the trace statistic case, while the alternative is slightly different instead. The trace statistic has been chosen over the maximum eigenvalue because it is more robust to skewness and excess kurthosis (a check has been done also with the maximum eigenvalue statistic and the result does not change). We chose a lag length of 21 because it allows us to check for any monthly dependence between the variables.

Just like with the unit root tests, we run this one with a constant term and without the trend option (as suggested by the AIC). The results are reported in table 5.4; 5% critical values are also reported.

[74] JOHANSEN S. (1991). *Estimation and Hypothesis Testing of Cointegration Vectors in Gaussian Vector Autoregressive Models. Econometrica*, 59, 1551–1580.

*Table 5.4. The Johansen test of cointegration*

| MAXIMUM RANK | EIGENVALUE | TRACE STATISTIC | 5% CRITICAL VALUE |
|---|---|---|---|
| **0** | . | 30.7567 | 29.68 |
| **1** | 0.01397 | 9.0391* | 15.41 |
| **2** | 0.00438 | 2.2556 | 3.76 |
| **3** | 0.00146 | | |

The results of the test are clear: at 5% critical value, we reject the null hypothesis of no cointegration while we fail to reject the null hypothesis of one cointegration equation; at rank one in fact the trace statistic is lower than the 5% critical value. Our variables are therefore characterized by one cointegrating relationship.

Once the cointegration has been detected we know that there exists a long-term equilibrium relationship between the series, we can therefore apply the VECM in order to evaluate the short run properties of the cointegrated series.

Given the characteristics of our variables, we can apply the appropriate restrictions to (4.20)[75], obtaining

$$\Delta y_t = \alpha(\beta' y_{t-1} + \mu) + \sum_{i=1}^{p-1} \Gamma_i \Delta y_{t-i} + \varepsilon_t \quad (5.1)$$

which, in our case, generates three equations, one for each variable.

$$\Delta logPun_t = \alpha_1(\beta_1 logPun_{t-1} - \beta_2 logGas_{t-1} - \beta_3 logEUA_{t-1} + \mu) + \sum_{i=1}^{p-1} \Gamma_{i1} \Delta logPun_{t-i} + \sum_{i=1}^{p-1} \Gamma_{i2} \Delta logGas_{t-i} + \sum_{i=1}^{p-1} \Gamma_{i3} \Delta logEUA_{t-i} + \varepsilon_t \quad (5.2)$$

[75] We assume that that there are no linear time trends in our variables. We therefore allow the cointegration equations to be stationary around a constant mean but without allowing any other trends or constant terms.

$$\Delta logGas_t = \alpha_2(\beta_1 logPun_{t-1} - \beta_2 logGas_{t-1} - \beta_3 logEUA_{t-1} + \mu) + \sum_{i=1}^{p-1} \Gamma_{i1}\Delta logPun_{t-i} + \sum_{i=1}^{p-1} \Gamma_{i2}\Delta logGas_{t-i} + \sum_{i=1}^{p-1} \Gamma_{i3}\Delta logEUA_{t-i} + \varepsilon_t \qquad (5.3)$$

$$\Delta logEUA_t = \alpha_3(\beta_1 logPun_{t-1} - \beta_2 logGas_{t-1} - \beta_3 logEUA_{t-1} + \mu) + \sum_{i=1}^{p-1} \Gamma_{i1}\Delta logPun_{t-i} + \sum_{i=1}^{p-1} \Gamma_{i2}\Delta logGas_{t-i} + \sum_{i=1}^{p-1} \Gamma_{i3}\Delta logEUA_{t-i} + \varepsilon_t \qquad (5.4)$$

The three equations contain both I(1) terms, the lag of the variables, and both I(0) terms, which correspond to the differenced variables and their lags. As already mentioned, the model has been run with a lag length of 21, because we believe that the allowances price may take some time to influence the PUN price given the way in which allowances are sold. With such a long time span we are able to check if there is any monthly correlation between our variables of interest. The restrictions imposed assure that there are no linear time trends in the levels of the data. Besides, the cointegrating equations are stationary around a mean.

As discussed by Johansen (1955)[76], to identify the parameters in β, at least $r^2$ restriction are needed. Therefore, the Johansen normalization restriction has been imposed.

## 5.3 The specification of the model

Before analyzing the results of the model, we checked whether the model was well specified through some postestimation tests. More precisely, we decided to verify if the residuals of the model were not auto-correlated and, later, if the short-term variables were jointly significant. The failure of this type of analysis would suggest that we have to check the hypothesis on which our analysis is based.

With the Lagrange-Multiplier test, we controlled if there was no auto-correlation in the residuals, the null hypothesis of the test. The results are reported in the appendix[77]. As it can be noted, almost all the p-values are above the 5% critical value: this led us to fail to reject the null-hypothesis of no auto-correlation. It’s therefore not a strong assumption to assume that the residuals are no auto-correlated. Thus, this test finds no evidence of model misspecification.

[76] JOHANSEN S. (1955). *Likelihood-Based inference in cointegrated vector autoregressive models.* Oxford University Press.
[77] Appendix A

Also, the overall significance of the short-term values has been checked through a Wald test, as suggested by Judge et al. (1985)[78]. The test statistic follows a chi-squared distribution with q degrees of freedom, where q denotes the number of linear hypothesis to be tested jointly. A test has been run for each variable in the first equation (5.2), checking for the jointly significance of all the lags of that variable. The null hypothesis is therefore that all lags are jointly equal to 0. Results are reported in the following table

*Table 5.5. The Wald test*

| VARIABLE | LAGS | CHI2(20) | PROB>CHI2 |
|---|---|---|---|
| **ΔLOGPUN** | 20 | 159.79 | 0.0000 |
| **ΔLOGGAS** | 20 | 42.44 | 0.0024 |
| **ΔLOGEUA** | 20 | 37.01 | 0.0117 |

As it can be noted from the table, all the p-values are below the 5% critical value. Hence, we reject the null-hypothesis of all lags equal to 0 for every variable of the first equation. This means that the electricity price is significantly correlated to the short-term lags. Besides, this test also does not provide any proof of misspecification in the model. We can therefore conclude that the model has been correctly defined.

## 4.6 Results

As it has already been stated, there are several steps through which a Vector Error Correction Model can be implemented. The results of the unit root tests confirmed that all the time series we were using were non-stationary I(1) processes. This allowed us to use the Johansen test for cointegration and identify one cointegrating relationship among the variables. Established so, we finally run the VECM. The model has been restricted so that no linear time trends to the levels of the data were possible; this restriction reflects the nature of our time series and it's

[78] JUDGE G.G, GRIFFITHS W.E, HILL R.C, LUTKEPOHL H. and LEE T-C. (1985). *The Theory and Practice of Econometrics*. 2nd ed.

confirmed by the information criteria used. Besides, to exactly identify the parameter β, the Johansen normalization restriction has been imposed. The Lagrange-multiplier test and a Wald test run on the short-term variables assured us about the well-specification of the model, while, an analysis of the Impulse Response Functions allowed us to better identify the nature of the causality between our variables of interest.

The output of the model is fully reported in the appendix[79]. We will discuss here the results of the long run relationship relative to the first equation (5.2), our equation of interest. Note that since the model has been run in logarithms, all values can be interpreted as elasticities.

Using our previous notation, we have estimated

$$\hat{\alpha} = (-0.089, -0.0007, 0.0045)$$

$$\hat{\beta} = (1, 0.72622, 0.2061)$$

$$\hat{v} = (5.40e - 06, -0.0002, 0.00007)$$

Where α is the vector of adjustment factors, β is the cointegrating vector and ν is the vector of the (restricted) constants. Be

The cointegrating equation instead is given by the following table

*Table 5.6. The cointegrating equation*

| BETA | COEF. | STD. ERR. | Z | P>\|Z\| |
|---|---|---|---|---|
| LOGPUN | 1 | . | . | . |
| LOGGAS | -0.7262246 | 0.1169063 | -6.21 | 0.000 |
| LOGEUA | -0.206151 | 0.120413 | -1.71 | 0.087 |
| _CONS | -1.445163 | . | . | . |

[79] Appendix B. The output of the model.

Hence, the long run relationship can be summarized as follow

$$logPun = 1.44 + 0.72logGas + 0.20logEUA + \varepsilon_t \quad (5.6)$$

Overall, results confirm that the model fits well. In fact, all the variables in the cointegrating equation are significant with a p-value below the 10% threshold. Besides, the signs of long-run coefficients are perfectly in line with other similar studies (Lo Prete and Norman, 2013, among others)[80]. The significance of the first value in the α vector indicates that a long run causality running towards the pun from the other variables exists. More precisely it indicates that when the average electricity price is too high, it slowly falls back towards the equilibrium. Also, some short run relationships can be identified given the significance of the lagged variables.

Equation 5.6 confirms our expectations about the relationship between the variables. In particular, an increase in the natural gas price and in the price of the allowances cause an increase in the Italian electricity price. Natural gas has a huge impact on the electricity price: a 1% increase in the gas price produce in the long-run a 0.72% increase in the pun price. On the other hand, the impact of the allowances is lower: a 1% increase in the EUA is reflected in a 0.20% increase in the Italian electricity price.

## 4.5 Impulse Response Functions (IRFs)

Finally, in order to complete our analysis, the impulse response functions can be estimated and interpreted, as it is explained in detail by Lutkepohl (1993)[81]. In fact, in applied work, it is often of interest to know the response of one variable to an impulse in another variable in a system that involves a number of further variables as well. An IRF measures the impact of a unit increase in an exogenous variable on the endogenous variables over time. Note that whereas IRFs from a stationary VAR die out over time, in a cointegrating VECM this does not always happen. In fact, the I(1) variables modeled in our work are not mean reverting, and this implies that some shocks may not die out over time. IRFs are important because they allow us to identify the direction of the causality between the variables.

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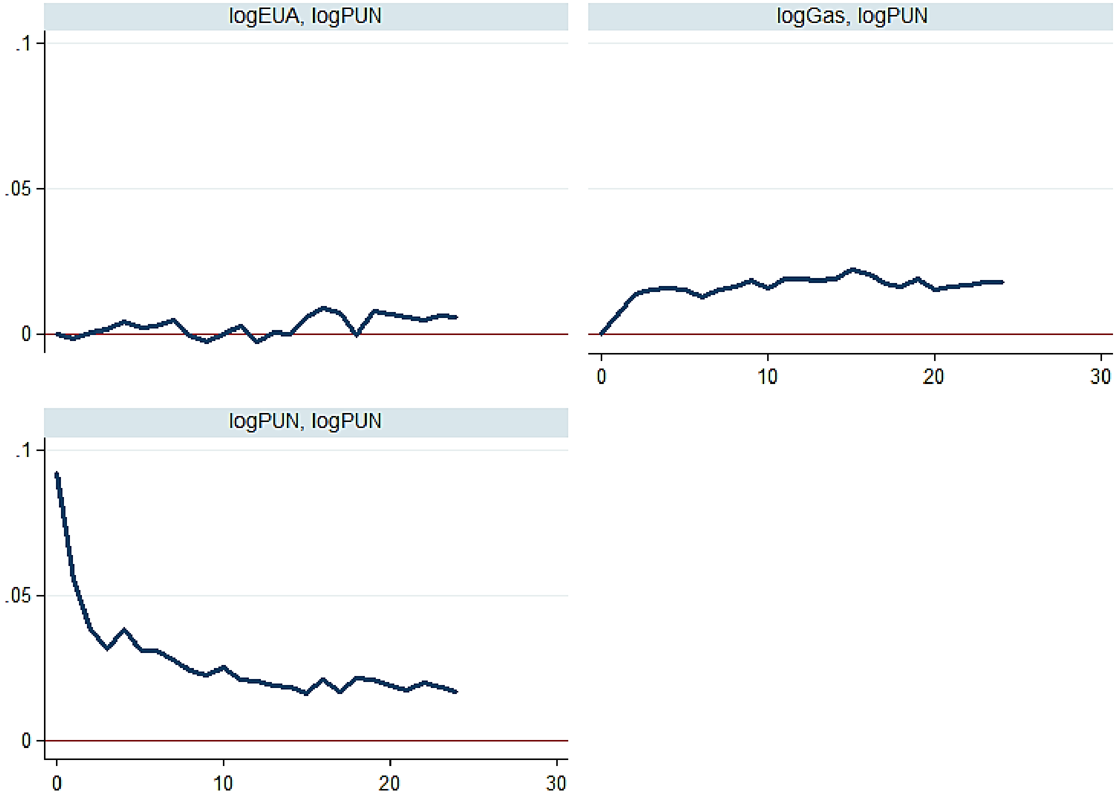
[80] LO PRETE C., NORMAN C.S. (2013). *Rockets and feathers in power future markets? Evidence from the second phase of the EU ETS*. Energy Economics, 36, pp. 312-321.

[81] LUTKEPOHL H. (1993) 2nd ed. *Introduction to Multiple Time Series Analysis*. New York, Springer.

A problematic assumption of this type of analysis is that only one variable at a time is affected by a shock. This may not be realistic if the shocks in different variables are not independent. That's the reason why we have decided to use orthogonalized shocks, which assume that a change in one component doesn't have any effect on other components because the components are orthogonal (uncorrelated).

In the following figures, firstly the effects of an orthogonalized shock in the variables towards the logPun are presented, then the opposite case is shown.

*Figure 5.2. The effects of orthogonalized shocks on the PUN variable*



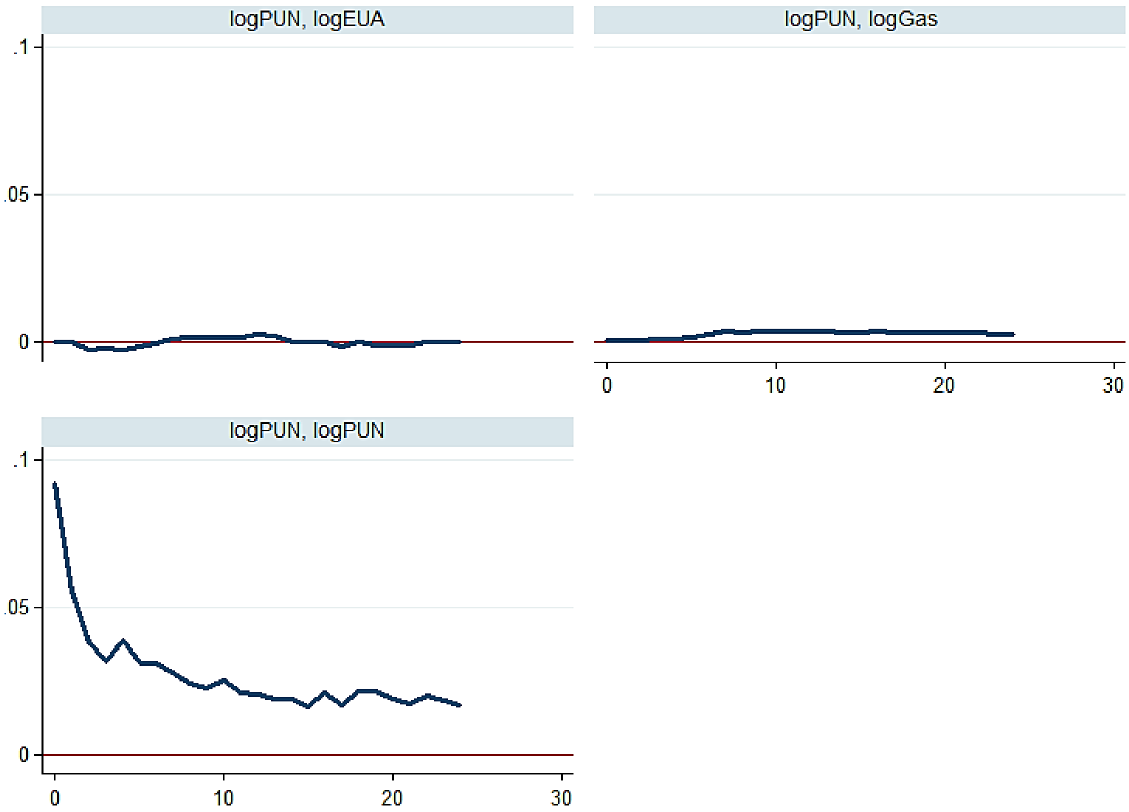

Graph by Impulse variable and Response variable.

As can be noted from the three graphs, an orthogonalized shock in each variable has effects on the logPun. The shocks in the Pun and Natural Gas variable have a clear positive effect on the electricity price, the former with a greater magnitude than the latter. On the contrary, the effect of an orthogonalized shock in the allowances prices on the Pun variable is not that clear. The graph seems to confirm that a change in the allowance price takes some days to have an effect on the Italian electricity price in the short-run and this effect seems to be mainly positive.

Therefore, even if with different magnitudes, all the three shocks are likely to have permanent effects on the Prezzo Unico Nazionale. The greatest magnitude is given by a shock in the logPun variable itself, while the lowest, is given by the variable logEUA. According to this model, shocks in the average Italian electricity price, gas future price and allowances price, are likely to have a permanent effect on the average national electricity price in Italy. In order to be sure about the direction of the causality between the series, also the opposite case must be analyzed.

In the figure 3, effects of an orthogonalized shock in the electricity price is shown.

*Figure 5.3. The effects of an orthogonalized shock in the PUN variable*




Graph by Impulse variable and Response variable.

As expected, an orthogonalized shock in the PUN variable does not influence the allowances price and the natural gas future price. This is in line with the economics theory and outlines the direction of the causality between our variables. We can therefore conclude that while the allowances price and the natural effect price directly influence the Italian electricity price, the opposite case is not true.

# 6. Conclusions

The EU Emission System, firstly introduced in 2005, it's now at its third phase after a continuous process of refinement and improvement. In its attempt to reach the goals it has established, the system exercises a strong influence in many markets in the European area. In fact, carbon prices raise costs associated with pollution and this can impact the competitiveness of certain industrial sectors.

The overall electricity sector reacted to these higher costs by passing them on the electricity price and this is the reason why from 2012 the electricity market is subject to a 100% auctioning of the allowances. This change in policy could have had effects on the pass-through level and on the magnitude of this phenomenon and this is something that we decided to investigate.

Our study analysed the relationship between the price of the allowances and the electricity price in the Italian market, which is one of the biggest European market in terms of size and electricity price level. All the time series we were using proved to be non-stationary I(1) processes and this is why we decided to use the maximum-likelihood technique developed by Johansen in the estimation of a Vector Error Correction Model.

The results of our model confirmed that the EUAs price has a direct effect on the Pun price, the national Italian electricity price, also in the third phase of the EU ETS. More precisely, a 1% increase in the allowances price causes a 0.20% increase in the power price. This indeed is something we were expecting, since the costs associated with pollution have been already internalized by power suppliers during the first phases of the system.

The results of our work confirm an overall heterogeneity in the response of the electricity generation sector to the new mechanisms introduced by the EU ETS. The pass-through effect we found is consistent with the work of many other researchers (e.g. Fabra and Reguant, 2014, among others)[82] even if the magnitude can differ depending on the country and on the type of data used.

A country's electricity production mix could play an essential role in explaining different levels of passing-through. In fact, electricity prices can be more sensitive to carbon constraints when the composition of the energy mix is characterized by the predominance of fossil energy

[82] FABRA N. and REGUANT M. (2014). Pass-through of Emissions Costs in Electricity Markets. American Economic Review, 104, pp. 2872-2899.

sources. On the contrary, when non-fossil energy power stations are the main source of production there is less need to use emission permits. In Italy, a relatively low level of passing-through can be explained by a decreasing use of Natural Gas and Oil as a source of production over time and by an increasing share of renewables (accounting for almost 40% of the total sources of production).

Finally, we wish to stress the fact that an increase in the electricity price due to an increase in the allowances price is efficient. Higher power prices in fact induce consumers to reduce their demand for carbon-generated electricity and producers to seek for least costs abatement options. This is perfectly in line with the scope of the EU Emission Trading System.

# Appendix A. Results of the tests

*Table A.1. Information Criteria*

| VARIABLE | AIC | HQIC | SBIC |
|---|---|---|---|
| LOGPUN | 4 | 4 | 4 |
| LOGGAS | 4 | 2 | 1 |
| LOGEUA | 3 | 3 | 1 |

Table A.1 reports the results of different information criteria applied to our variables of interest. In our research we mainly followed the AIC, even if a comparison with other information criteria has been often carried out.

*Table A.2. Unit root tests*

| VARIABLE | TEST | LAG | TEST STATISTIC | ACCEPT H0, C.I | C.I |
|---|---|---|---|---|---|
| LOGPUN | ADF | 3 | -4,46 | No | . |
| LOGPUN | PP | 3 | -6,603 | No | . |
| LOGPUN | DF-GLS | 3 | -2,272 | Yes | 1% |
| LOGGAS | ADF | 2 | -1.853 | Yes | 10% |
| LOGGAS | PP | 2 | -1.878 | Yes | 10% |
| LOGEUA | ADF | 2 | -2,515 | Yes | 10% |
| LOGEUA | PP | 2 | -2,754 | Yes | 5% |
| LOGEUA | DF-GLS | 2 | -2,351 | Yes | 10% |
| LOGPUN | KPSS | 3 | 14.7 | No | 10% |
| LOGEUA | KPSS | 2 | 2.88 | No | 10% |
| LOGGAS | KPSS | 3 | 27 | No | 10% |
| LOGPUN | KPSS | 3 | 14.7 | No | 10% |

All the unit root tests have been run without the trend option and around a constant. Variables were not sensitive to the presence of a trend though. Gas and allowances prices show a strong evidence of non-stationarity while the behavior of the Pun variable is more ambiguous. This can arise from the fact that the electricity variable was obtained through a sequence of weighted averages; this could have softened its characteristics. That's' the reason why also the KPSS test has been run.

*Table A.3. The Lagrange-multiplier test*

| LAG | CHI2 | DF | PROB > CHI2 |
|---|---|---|---|
| **1** | 6.5800 | 9 | 0.68075 |
| **2** | 7.9348 | 9 | 0.54073 |
| **3** | 9.0972 | 9 | 0.42835 |
| **4** | 9.0176 | 9 | 0.43565 |
| **5** | 14.0204 | 9 | 0.12160 |
| **6** | 6.9798 | 9 | 0.63922 |
| **7** | 18.5225 | 9 | 0.02957 |
| **8** | 6.7183 | 9 | 0.66642 |
| **9** | 15.3529 | 9 | 0.08169 |
| **10** | 5.1599 | 9 | 0.82015 |
| **11** | 6.3081 | 9 | 0.70873 |
| **12** | 9.1191 | 9 | 0.42635 |
| **13** | 8.8117 | 9 | 0.45484 |
| **14** | 23.8872 | 9 | 0.00448 |
| **15** | 2.9998 | 9 | 0.96430 |
| **16** | 18.3307 | 9 | 0.03153 |
| **17** | 5.4963 | 9 | 0.78908 |
| **18** | 13.1251 | 9 | 0.15703 |
| **19** | 11.8504 | 9 | 0.22187 |
| **20** | 9.4060 | 9 | 0.40067 |
| **21** | 4.4623 | 9 | 0.87844 |

The Lagrange-multiplier test has a null-hypothesis of no auto-correlation in the residuals for a given lag. Since we obtained small p-values in almost each lag, we fail to reject the null of no auto-correlation in the residuals. Overall, it’s not a strong assumption to assume we are in presence of no auto-correlation.

# Appendix B. The output of the model

*Table B.1. The first equation*

| | Coef. | Std. Err. | z | P>\|z\| |
|---|---|---|---|---|
| **D_logPUN** | | | | |
| **_ce1** | | | | |
| **L1.** | -.0894145 | .0197065 | -4.54 | 0.000 |
| **logPUN** | | | | |
| **LD.** | -.313103 | .0306494 | -10.22 | 0.000 |
| **L2D.** | -.2607936 | .0316259 | -8.25 | 0.000 |
| **L3D.** | -.2035433 | .0324381 | -6.27 | 0.000 |
| **L4D.** | -.0486016 | .0328044 | -1.48 | 0.138 |
| **L5D.** | -.1019768 | .0328853 | -3.10 | 0.002 |
| **L6D.** | -.0434326 | .0327686 | -1.33 | 0.185 |
| **L7D.** | -.0615025 | .0327133 | -1.88 | 0.060 |
| **L8D.** | -.0918352 | .0326058 | -2.82 | 0.005 |
| **L9D.** | -.0759727 | .0325423 | -2.33 | 0.020 |
| **L10D.** | -.0479196 | .0323762 | -1.48 | 0.139 |
| **L11D.** | -.0736583 | .032333 | -2.28 | 0.023 |
| **L12D.** | -.0542921 | .0322821 | -1.68 | 0.093 |
| **L13D.** | -.0585034 | .0320136 | -1.83 | 0.068 |
| **L14D.** | -.0612347 | .031773 | -1.93 | 0.054 |
| **L15D.** | -.0628691 | .0316313 | -1.99 | 0.047 |
| **L16D.** | -.0023948 | .0312764 | -0.08 | 0.939 |
| **L17D.** | -.0415499 | .0311442 | -1.33 | 0.182 |
| **L18D.** | .0344528 | .0302088 | 1.14 | 0.254 |
| **L19D.** | .0284434 | .0285797 | 1.00 | 0.320 |
| **L20D.** | -.0121389 | .0263339 | -0.46 | 0.645 |
| | | | | |
| **logGas** | | | | |
| **LD.** | .3885818 | .1529069 | 2.54 | 0.011 |
| **L2D.** | .5605363 | .1537264 | 3.65 | 0.000 |
| **L3D.** | .3694915 | .1543708 | 2.39 | 0.017 |
| **L4D.** | .2639608 | .1548632 | 1.70 | 0.088 |
| **L5D.** | .1515499 | .1551046 | 0.98 | 0.329 |
| **L6D.** | -.0868002 | .1549693 | -0.56 | 0.575 |
| **L7D.** | .1808339 | .155546 | 1.16 | 0.245 |

| | | | | |
|---|---|---|---|---|
| **L8D.** | .2581466 | .1555155 | 1.66 | 0.097 |
| **L9D.** | .3128453 | .1555874 | 2.01 | 0.044 |
| **L10D.** | -.003063 | .1559185 | -0.02 | 0.984 |
| **L11D.** | .2060595 | .155804 | 1.32 | 0.186 |
| **L12D.** | .0807935 | .1554033 | 0.52 | 0.603 |
| **L13D.** | .0420264 | .1555973 | 0.27 | 0.787 |
| **L14D.** | .1376371 | .1551262 | 0.89 | 0.375 |
| **L15D.** | .2940199 | .1541207 | 1.91 | 0.056 |
| **L16D.** | .0765762 | .1543418 | 0.50 | 0.620 |
| **L17D.** | -.1229012 | .1542624 | -0.80 | 0.426 |
| **L18D.** | -.0370783 | .1540098 | -0.24 | 0.810 |
| **L19D.** | .0624064 | .153833 | 0.41 | 0.685 |
| **L20D.** | -.1966882 | .1530834 | -1.28 | 0.199 |

| | | | | |
|---|---|---|---|---|
| **logEUA** | | | | |
| **LD.** | -.0533088 | .0716545 | -0.74 | 0.457 |
| **L2D.** | -.0021307 | .0719072 | -0.03 | 0.976 |
| **L3D.** | .002884 | .0720726 | 0.04 | 0.968 |
| **L4D.** | .0631006 | .0720314 | 0.88 | 0.381 |
| **L5D.** | -.0442208 | .0720291 | -0.61 | 0.539 |
| **L6D.** | -.0014606 | .072113 | -0.02 | 0.984 |
| **L7D.** | .0659514 | .0720083 | 0.92 | 0.360 |
| **L8D.** | -.1582806 | .0719065 | -2.20 | 0.028 |
| **L9D.** | -.1092744 | .0717231 | -1.52 | 0.128 |
| **L10D.** | -.0259482 | .0718064 | -0.36 | 0.718 |
| **L11D.** | .0124202 | .0717926 | 0.17 | 0.863 |
| **L12D.** | -.1557891 | .0716945 | -2.17 | 0.030 |
| **L13D.** | .0489241 | .0719582 | 0.68 | 0.497 |
| **L14D.** | -.0513903 | .072069 | -0.71 | 0.476 |
| **L15D.** | .1388174 | .0721396 | 1.92 | 0.054 |
| **L16D.** | .1446192 | .0721044 | 2.01 | 0.045 |
| **L17D.** | .0345653 | .0721124 | 0.48 | 0.632 |
| **L18D.** | -.1785054 | .0720164 | -2.48 | 0.013 |
| **L19D.** | .1637515 | .0717088 | 2.28 | 0.022 |
| **L20D.** | -.0548132 | .0716917 | -0.76 | 0.445 |
| **_cons** | 5.40e-06 | .0023496 | 0.00 | 0.998 |

*Table B.2. The second equation*

| | Coef. | Std. Err. | z | P>\|z\| |
|---|---|---|---|---|
| **D_logGas** | | | | |
| **_ce1** | | | | |
| **L1.** | -.0007553 | .0033761 | -0.22 | 0.823 |
| **logPUN** | | | | |
| **LD.** | .0047644 | .0052508 | 0.91 | 0.364 |
| **L2D.** | .0026814 | .0054181 | 0.49 | 0.621 |
| **L3D.** | .0063057 | .0055572 | 1.13 | 0.257 |
| **L4D.** | .0026922 | .00562 | 0.48 | 0.632 |
| **L5D.** | .0124392 | .0056339 | 2.21 | 0.027 |
| **L6D.** | .0165568 | .0056139 | 2.95 | 0.003 |
| **L7D.** | .0181143 | .0056044 | 3.23 | 0.001 |
| **L8D.** | .0071603 | .005586 | 1.28 | 0.200 |
| **L9D.** | .0106346 | .0055751 | 1.91 | 0.056 |
| **L10D.** | .0054771 | .0055466 | 0.99 | 0.323 |
| **L11D.** | .0065538 | .0055392 | 1.18 | 0.237 |
| **L12D.** | .0071017 | .0055305 | 1.28 | 0.199 |
| **L13D.** | .0085749 | .0054845 | 1.56 | 0.118 |
| **L14D.** | .0036393 | .0054433 | 0.67 | 0.504 |
| **L15D.** | .0039584 | .005419 | 0.73 | 0.465 |
| **L16D.** | .004951 | .0053582 | 0.92 | 0.355 |
| **L17D.** | -.000994 | .0053356 | -0.19 | 0.852 |
| **L18D.** | .0062722 | .0051753 | 1.21 | 0.226 |
| **L19D.** | .001083 | .0048962 | 0.22 | 0.825 |
| **L20D.** | .0080944 | .0045115 | 1.79 | 0.073 |
| | | | | |
| **logGas** | | | | |
| **LD.** | -.0681808 | .0261958 | -2.60 | 0.009 |
| **L2D.** | .0274529 | .0263361 | 1.04 | 0.297 |
| **L3D.** | .0611529 | .0264465 | 2.31 | 0.021 |
| **L4D.** | -.0579945 | .0265309 | -2.19 | 0.029 |
| **L5D.** | .023238 | .0265723 | 0.87 | 0.382 |
| **L6D.** | -.0913767 | .0265491 | -3.44 | 0.001 |
| **L7D.** | -.0121926 | .0266479 | -0.46 | 0.647 |
| **L8D.** | .010286 | .0266427 | 0.39 | 0.699 |

| | | | | |
|---|---|---|---|---|
| **L9D.** | .0501788 | .026655 | 1.88 | 0.060 |
| **L10D.** | .0639014 | .0267117 | 2.39 | 0.017 |
| **L11D.** | .0268318 | .0266921 | 1.01 | 0.315 |
| **L12D.** | -.0176752 | .0266234 | -0.66 | 0.507 |
| **L13D.** | -.0261839 | .0266567 | -0.98 | 0.326 |
| **L14D.** | -.0102918 | .026576 | -0.39 | 0.699 |
| **L15D.** | .0382559 | .0264037 | 1.45 | 0.147 |
| **L16D.** | -.0308797 | .0264416 | -1.17 | 0.243 |
| **L17D.** | -.0277455 | .026428 | -1.05 | 0.294 |
| **L18D.** | -.0086259 | .0263847 | -0.33 | 0.744 |
| **L19D.** | .016187 | .0263544 | 0.61 | 0.539 |
| **L20D.** | .0437863 | .026226 | 1.67 | 0.095 |
| | | | | |
| **logEUA** | | | | |
| **LD.** | .0431048 | .0122757 | 3.51 | 0.000 |
| **L2D.** | .0029423 | .012319 | 0.24 | 0.811 |
| **L3D.** | .0129713 | .0123474 | 1.05 | 0.293 |
| **L4D.** | .0083216 | .0123403 | 0.67 | 0.500 |
| **L5D.** | -.0083072 | .0123399 | -0.67 | 0.501 |
| **L6D.** | -.0200813 | .0123543 | -1.63 | 0.104 |
| **L7D.** | .0162352 | .0123363 | 1.32 | 0.188 |
| **L8D.** | -.0081116 | .0123189 | -0.66 | 0.510 |
| **L9D.** | .0139454 | .0122875 | 1.13 | 0.256 |
| **L10D.** | -.0025347 | .0123017 | -0.21 | 0.837 |
| **L11D.** | .0087652 | .0122994 | 0.71 | 0.476 |
| **L12D.** | -.0112428 | .0122826 | -0.92 | 0.360 |
| **L13D.** | .0067738 | .0123278 | 0.55 | 0.583 |
| **L14D.** | -.0005259 | .0123467 | -0.04 | 0.966 |
| **L15D.** | .0182289 | .0123588 | 1.47 | 0.140 |
| **L16D.** | .0079373 | .0123528 | 0.64 | 0.521 |
| **L17D.** | .0121104 | .0123542 | 0.98 | 0.327 |
| **L18D.** | -.0026971 | .0123377 | -0.22 | 0.827 |
| **L19D.** | -.0053208 | .012285 | -0.43 | 0.665 |
| **L20D.** | -.0171113 | .0122821 | -1.39 | 0.164 |
| **_cons** | -.0002259 | .0004025 | -0.56 | 0.575 |

*Table B.3. The third equation*

| | Coef. | Std. Err. | z | P>\|z\| |
|---|---|---|---|---|
| **D_logEUA** | | | | |
| **_ce1** | | | | |
| **L1.** | .00449 | .0071647 | 0.63 | 0.531 |
| **logPUN** | | | | |
| **LD.** | -.002232 | .0111432 | -0.20 | 0.841 |
| **L2D.** | -.0317971 | .0114982 | -2.77 | 0.006 |
| **L3D.** | -.0111826 | .0117935 | -0.95 | 0.343 |
| **L4D.** | -.017972 | .0119267 | -1.51 | 0.132 |
| **L5D.** | -.0041222 | .0119561 | -0.34 | 0.730 |
| **L6D.** | .0097171 | .0119137 | 0.82 | 0.415 |
| **L7D.** | .0148788 | .0118936 | 1.25 | 0.211 |
| **L8D.** | .016003 | .0118545 | 1.35 | 0.177 |
| **L9D.** | .0077546 | .0118314 | 0.66 | 0.512 |
| **L10D.** | .0044317 | .011771 | 0.38 | 0.707 |
| **L11D.** | .0041009 | .0117553 | 0.35 | 0.727 |
| **L12D.** | .0074766 | .0117368 | 0.64 | 0.524 |
| **L13D.** | -.0018216 | .0116392 | -0.16 | 0.876 |
| **L14D.** | -.0225961 | .0115517 | -1.96 | 0.050 |
| **L15D.** | -.0145301 | .0115002 | -1.26 | 0.206 |
| **L16D.** | -.0188911 | .0113711 | -1.66 | 0.097 |
| **L17D.** | -.0253607 | .0113231 | -2.24 | 0.025 |
| **L18D.** | .0010052 | .010983 | 0.09 | 0.927 |
| **L19D.** | -.0155872 | .0103907 | -1.50 | 0.134 |
| **L20D.** | -.0084442 | .0095742 | -0.88 | 0.378 |
| | | | | |
| **logGas** | | | | |
| **LD.** | -.0230025 | .0555923 | -0.41 | 0.679 |
| **L2D.** | -.0054562 | .0558903 | -0.10 | 0.922 |
| **L3D.** | .032529 | .0561246 | 0.58 | 0.562 |
| **L4D.** | -.0226988 | .0563036 | -0.40 | 0.687 |
| **L5D.** | -.0057197 | .0563914 | -0.10 | 0.919 |
| **L6D.** | .0309259 | .0563422 | 0.55 | 0.583 |
| **L7D.** | -.0152446 | .0565518 | -0.27 | 0.787 |
| **L8D.** | .0375618 | .0565407 | 0.66 | 0.506 |

| | | | | |
|---|---|---|---|---|
| **L9D.** | -.0366722 | .0565669 | -0.65 | 0.517 |
| **L10D.** | .0594665 | .0566872 | 1.05 | 0.294 |
| **L11D.** | -.0449832 | .0566456 | -0.79 | 0.427 |
| **L12D.** | -.0442112 | .0564999 | -0.78 | 0.434 |
| **L13D.** | .0616716 | .0565705 | 1.09 | 0.276 |
| **L14D.** | .0025643 | .0563992 | 0.05 | 0.964 |
| **L15D.** | .047815 | .0560336 | 0.85 | 0.393 |
| **L16D.** | .0624747 | .056114 | 1.11 | 0.266 |
| **L17D.** | -.002541 | .0560851 | -0.05 | 0.964 |
| **L18D.** | -.0398979 | .0559933 | -0.71 | 0.476 |
| **L19D.** | .0363766 | .055929 | 0.65 | 0.515 |
| **L20D.** | .1482752 | .0556565 | 2.66 | 0.008 |
| | | | | |
| **logEUA** | | | | |
| **LD.** | -.0139852 | .0260514 | -0.54 | 0.591 |
| **L2D.** | -.1028751 | .0261433 | -3.94 | 0.000 |
| **L3D.** | -.0441083 | .0262034 | -1.68 | 0.092 |
| **L4D.** | .0729821 | .0261885 | 2.79 | 0.005 |
| **L5D.** | .0403972 | .0261876 | 1.54 | 0.123 |
| **L6D.** | .0078233 | .0262181 | 0.30 | 0.765 |
| **L7D.** | .0230398 | .02618 | 0.88 | 0.379 |
| **L8D.** | .0293599 | .026143 | 1.12 | 0.261 |
| **L9D.** | .0279963 | .0260763 | 1.07 | 0.283 |
| **L10D.** | -.0014404 | .0261066 | -0.06 | 0.956 |
| **L11D.** | .0212923 | .0261016 | 0.82 | 0.415 |
| **L12D.** | -.0817791 | .026066 | -3.14 | 0.002 |
| **L13D.** | -.0529481 | .0261618 | -2.02 | 0.043 |
| **L14D.** | -.0681202 | .0262021 | -2.60 | 0.009 |
| **L15D.** | .0035608 | .0262278 | 0.14 | 0.892 |
| **L16D.** | -.0505169 | .026215 | -1.93 | 0.054 |
| **L17D.** | -.0163046 | .0262179 | -0.62 | 0.534 |
| **L18D.** | -.0682474 | .026183 | -2.61 | 0.009 |
| **L19D.** | -.0008468 | .0260711 | -0.03 | 0.974 |
| **L20D.** | -.0583626 | .0260649 | -2.24 | 0.025 |
| **_cons** | .0000695 | .0008542 | 0.08 | 0.935 |

*Table B.4. The cointegrating equation*

| BETA | COEF. | STD. ERR. | Z | P>Z |
|---|---|---|---|---|
| **LOGPUN** | 1 | . | . | . |
| **LOGGAS** | -.7262246 | .1169063 | -6.21 | 0.000 |
| **LOGEUA** | -.206151 | .120413 | -1.71 | 0.087 |
| **_CONS** | -1.445.163 | . | . | . |

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