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Essays on atmospheric emissions and environmental policy

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Chapter 1

Introduction

The work carried out in this dissertation focuses on different interactions between the economy, air emissions responsible for climate change, and policies to reduce them. The aim of this thesis is indeed to contribute to the debate on emissions and emissions reduction policies through four empirical studies. The following introduction provides, first of all, a brief outline on some current issues related to climate change and emissions control. In particular, Section 1.1 refers to the following topics: the problem of atmospheric contamination and climate change, the search for an international agreement allowing a comprehensive solution to this problem, and the main obstacles for this search to be successful. Section 1.2 focuses on the European Union (EU) position on climate change. After this brief outline, Section 1.3 describes the proposal of the different empirical analyses that form the thesis and their main contributions.

1.1. Climate change and obstacles to a global action

The problem of atmospheric pollution is one of the major concerns about damaging effects of human activities on the environment. Some of the gases released into the atmosphere, for example nitrogen oxides, sulphur oxides, or ammonia, are causing local and regional damages such as acid rain or acidification; other contaminants, known as greenhouse gases (GHGs), have a more global effect, mainly contributing to climate change.[1] Besides acid rain falls or global warming, atmospheric emissions can cause various damages.[2] Among them, climate change is perceived with particular concern due to the large-scale changes that it can cause in the ecosystem, such as glaciers melting and retreat, sea level rise, or changes in timing on seasonal events. These changes in the ecosystem are expected to have many negative and irreversible impacts for human beings, affecting for example health, provoking the spread of infectious diseases, changing water resources availability, agriculture and food production, or causing social and political conflicts.

The risks associated to climate change clearly need an international effort to be faced. Since the early 1970s, the awareness that human activities are plausibly responsible for climate change, its very negative consequences, and the expectation of further increases in atmospheric pollution have been a growing concern (Weart, 2008). Over time, scientific discussion reached political attention, and the worries of the international community took shape into the United Nations Framework Convention on Climate Change (UNFCCC), negotiated during the United Nation Conference on Environment held in 1992 in Rio de Janeiro. The main objective of this international environmental treaty was to "stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" (UNFCCC, 1992). This treaty created an international political framework to face the issue of air pollution and it recognized responsibilities that are shared but also differentiated among countries depending on their historical role in causing the current level of pollution.

To translate the common purpose of reducing emissions into effective actions, the more developed countries who were at that time responsible for

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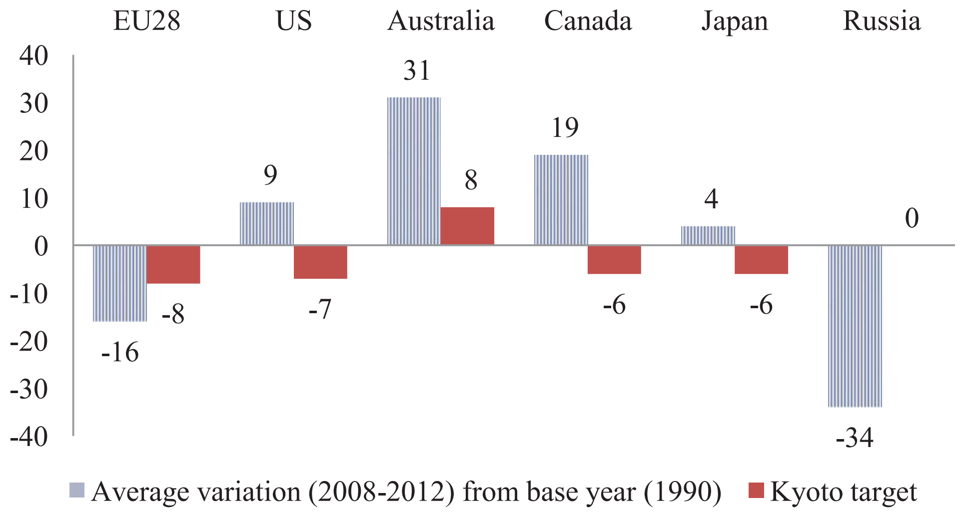
[1] The main GHGs are carbon dioxide (CO_2), nitrous oxide, methane, sulfur hexafluoride, chlorofluorocarbons, per-fluorocarbons, and hydro-fluorocarbons. Carbon dioxide, nitrous oxide, and methane are the most prevalent. Chlorofluorocarbon also contributes much to climate change as to the reduction of the ozone layer, but its release into the atmosphere was controlled effectively in the 80s with the Montreal Protocol. According to the 2013 report of the Intergovernmental Panel on Climate Change (IPCC), carbon dioxide emissions alone have caused roughly 73% of the change in energy fluxes causing global warming between 1750 and 2011 (IPCC, 2013).

[2] Some of the other damages caused by air pollution are, for example, the negative impact on health of smog, indoor air pollution, or other forms of atmospheric deposition.

most of the emissions (the so-called Annex-B countries) agreed to the Kyoto Protocol,[3] fixing legally binding obligations to reduce their greenhouse gas emissions, on average, to 5.2% less than the 1990 level in the period 2008-2012 (UNFCCC, 1998). The Kyoto Protocol was adopted in 1997, was enforced in 2005 - although the United States (US), at that time leader in GHG emissions, did not ratified the agreement - and it has been the only international agreement on climate change in force so far.

During the following yearly conferences, the UNFCCC Parties tried to create a stronger and binding legal framework for the post-Kyoto agreement period, in order to implement more effective policies of emissions reduction and to get more countries actively involved in it. This attempt was aimed at strengthening the effectiveness of the Kyoto Protocol since many countries did not reach their Kyoto targets (Figure 1.1).[4]

Figure 1.1. GHG variation in selected Annex-B countries, 1990-2012



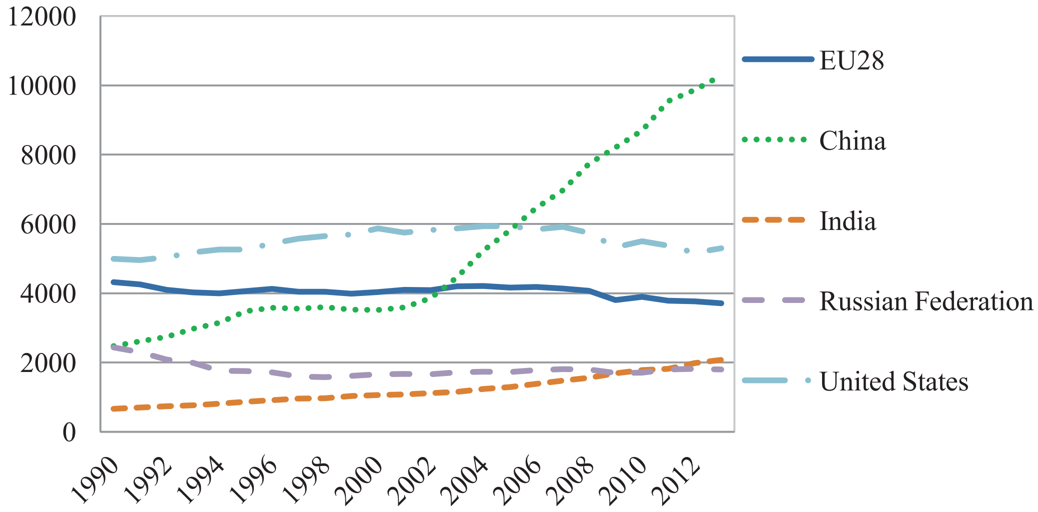
Unit: percentage variation.
Source: own elaboration from UNFCC data (UNFCCC, 2015).

[3] The 38 countries belonging to the Kyoto Protocol Annex B are Australia, Austria, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Lithuania, Liechtenstein, Luxembourg, Monaco, the Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine, United Kingdom, and the US.

[4] The EU28 countries are Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Croatia, Germany, Denmark, Spain, Estonia, Finland, France, United Kingdom, Greece, Hungary, Ireland, Italy, Lithuania, Luxembourg, Latvia, Malta, the Netherland, Poland, Portugal, Romania, Slovak Republic, Slovenia, and Sweden.

Moreover, although for regions like the EU the Kyoto Protocol was a relative success, some authors have found that a relevant share of the average emissions abatement for the Kyoto Protocol years was attributable to the effects of the economic crisis that took place since 2008/2009 (Höhne et al., 2009; Bel and Joseph, 2015). Finally and most important, the world volume of emissions is still increasing mainly due to countries that are not part of the Annex-B, such as China or India (Figure 1.2).

Figure 1.2. Evolution of CO_2 emissions



Unit: Millions of tons.
Five most polluting countries in 2013.
Source: own elaboration from EDGAR data (EDGAR, 2014).

Anyway, the political process to improve the international framework for emissions control has not produced any further treaty so far. There are indeed some important difficulties that have undermined the effectiveness of the Kyoto Protocol and are still preventing the success of the ongoing political process to strengthen it.

First, it is very difficult to implement effective political solutions to the global warming problem, because there is a time inconsistency between the short-term political perspectives and the long-term consequences, the intergenerational implications, and the high degree of uncertainty that the climate change issue implies. Or, in terms of cost-benefit of emissions reduction policy, there is a time asymmetry between its short-to-medium term cost and long-term benefit.

A second critical issue comes from the unsolved debate between more developed and developing countries about who should bear the cost of emissions reduction. It is true that the more developed countries have historically contributed to create air pollution most. It is also true that nowadays the role of developing countries in causing emissions to increase, especially given the size of their population, is very relevant. On total emissions, the relative weight of emissions from developing countries is in fact higher than the weight of emissions from more developed countries. To really deal with emissions reduction would need to get these countries actively involved too.

This issue becomes even more complex when trade is taken into account. Indeed, international trade and its share in world GDP is growing over time, so it is also contributing more to increase emissions. Peters et al. (2011), for example, analyzing the growth in emissions transfers via international trade, find that the emissions embodied in traded goods and services have increased from 20% of global emissions in 1990 to 26% in 2008. The growing amount of emissions embodied in trade intensifies the problem of emissions responsibility, which is one of the most problematic points in reaching an international agreement on emissions control: international trade creates a gap between production and consumption, and an increasing amount of goods is produced in places different from where it is finally consumed. If, on the one hand, developing countries are polluting more, on the other hand they are actually polluting to produce goods often consumed in developed countries. Many works that analyze the problem of atmospheric contamination (as for example Munksgaard and Pedersen, 2001; Baiocchi and Minx, 2010) affirm that trade flows entail emissions that might be taken into account at the time of establishing the responsibility of each country, and they wonder whether the responsibility for emissions has to be assigned to countries that actually emit polluting gases into the atmosphere, or to countries whose consumption makes these emissions necessary.

The third difficulty comes from the fact that climate change is a global negative externality that requires global actions to be solved. Indeed, if all the countries do not adopt the same measures, these measures might be ineffective as they might cause spillover effects such as carbon leakage: emissions might increase in regions that do not implement emissions reduction policies as a consequence of the emissions reduction in regions that do. Unilateral emissions reduction policies applied only locally, increasing the production cost of local producers, might pose a threat in terms of competitiveness. Countries can choose not to produce all products domestically, avoiding in this way part of their pollution and part of the cost associated to the emissions policies, and they can relocate the production of specific goods such as products that require intensive use of energy in foreign countries. This process is made even easier in the new production paradigm. As Baldwin (2014) suggests, the first globalization, made possible by the steam revolution, allowed the separation between production and consumption. Instead, the current change in global production, driven by the revolution in information and communication technologies, is characterized by specialization and fragmentation of the production processes at a global scale, making the separation of manufacturing stages possible and profitable. This new paradigm permits not only to reallocate some specific products, but also to reallocate some specific production stages, and these different stages have often also different ecological footprints.

Anyway, although on the one hand climate change requires global actions to be solved, on the other hand no global solution has been found so far: the UNFCCC treaty is legally non-binding and different countries have different priorities in environmental policies. Although countries signed the Kyoto Protocol to overcome this problem and some regions actually reached their objectives, the Kyoto Protocol did not fix penalties for countries who have not reached the emissions reduction targets. The international search for a global solution is now at stake. As the sole result produced by several attempts to reach a new agreement, some countries have maintained a compromise to reduce emissions to 2020 (Australia, all members of the EU28, Croatia, Iceland, Norway, and Switzerland); anyway big regions such as the US, Canada, Japan, New Zealand, and Russia are not involved in this commitment. Moreover, during the 17th Conference of the Parties in Durban in 2011, countries also committed themselves to sign a global agreement to take effect from 2020 during the Conference of the Parties in Paris in 2015. Only in December we will see if the international community will be able to turn these declarations of intent in a mandatory agreement.

The need for policies to reduce emissions makes it relevant the debate on different regional or national emissions control instruments. These tools can be of different nature. The more conventional approach is to apply command-and-control regulations that set targets that must be complied with, and negative sanctions that might result from their non-compliance. Other instruments make instead use of economic incentives, encouraging changes in behavior through market signals and allowing more flexibility in the means of achieving goals. While more conventional regulations usually set uniform standards for firms, economic-incentive instruments provide incentive for the biggest reduction in pollution to be by those firms that can achieve this reduction most cheaply (Stavins, 2001). To achieve the same cost-effective solution through command-and-control instruments the regulating authority would need detailed information about the firms' cost that is hardly available. In the absence of full information, the higher efficiency of incentive-based instruments makes those tools preferable. There are two main categories of economic-incentive instruments. Price instruments, such as a tax on the amount of pollution a firm generates, induce firms to reduce emissions up to the point where the marginal abatement cost is equal to the tax rate. Under quantity instruments, such as a tradable emissions permits (cap-and-trade) scheme, the overall level of pollution and the consequent permits are set and freely allocated or auctioned among firms that can use or sell them, letting the market determine their price.

1.2. The role of the European Union

In the absence of a binding global policy, regional proposals and initiatives become important. These are more significant the greater is the region that applies them. The EU has taken a stand on the subject of climate change since the 1980s when the European Commission issued its first communication on climate change, right after the first international conferences focused on this issue (European Commission, 1988).

After this first step, the EU tried to assume a leading role in the international effort to face climate change both by pushing international agreements to climate protection and by producing its own body of regulatory instruments. Indeed, as Böhringer (2014) shows, the European Community role turned out to be key in the negotiations for the UNFCCC adopted in 1992, in the Kyoto Protocol negotiations, or in the decisions agreed during the following Conferences of the Parties. Moreover, the EU has also contributed to the international commitment against climate change through the implementation of several regulatory instruments (Jordan et al., 2012). To maintain its commitment also after the end of the Kyoto Protocol phase, the European Parliament and Council set the current European targets for emissions reduction in 2009 (European Parliament and Council, 2009a). These targets, known as the "20-20-20" targets, fix three key objectives to be achieved by 2020: a 20% reduction in EU GHG emissions from 1990 levels; raising the share of EU energy consumption produced from renewable resources to 20%, and a 20% improvement in the EU's energy efficiency. Moreover, to provide also a long-term perspective on climate, energy, and transport, the European Commission came forward with three initiatives in 2011,[5] starting a further legislative process that set targets for longer-term, such as a reduction in emissions of 40% below 1990 levels by 2030, or a reduction equal to 80-95% below 1990 levels by 2050.

Anyway, the EU leading role in international negotiations on climate change and the ambitious goals that the European Community sets itself are in stark contrast with the lack of strong instruments that would be necessary to reach the EU ambitious targets (Jordan et al., 2012). Although the EU has implemented at European level both a minimum tax on the use of energy products and a system of emissions trading, the effectiveness of these tools remains inadequate. Regarding the European Community environmental taxation, the Energy Tax Directive (ETD) currently rules it (European Council, 2003) and fixes minimum rates that countries must take into account for their national implementations. Anyway, it remains limited in its nature of environmental policy by three main features. It contains a complex system of exemptions that reduce its effectiveness, it does not clearly reflect the content of emissions of the energy products taxed, and it lacks of coordination with the other instrument, set up later, which is the Emissions Trading System (ETS). The attempt of the European Commission to improve this tool and ride over its limits (European Commission, 2011d) has felt through. Regarding the ETS, this instrument, approved in 2003 (European Parliament and Council, 2003) and launched in

[5] These texts are the Roadmap for moving to a competitive low carbon economy in 2050 (European Commission, 2011a), the Energy Roadmap 2050 (European Commission, 2011b), and the Roadmap to a Single European Transport Area (European Commission, 2011c).

2005, has been defined as one of the EU's flagships of the climate change project (Vlachou, 2014). Anyway, although a major revision approved in 2009 tried to strengthen the system (European Parliament and Council, 2009b), the mechanism is now under many criticisms (see Branger et al., 2013). One of its weakest points is the volatility of allowance price over time, which has been much lower than expected during the last years. Without a credible and significant price signal both in the short and in the long term, the mechanism does not produce incentives that drive companies to adopt less contaminants technologies, thus failing to reduce emissions.

The price of CO_2 emissions is illustrative to exemplify the contradiction that exists between the objectives of reducing emissions that the EU seeks and the instruments implemented to date. On the one hand, the average price of CO_2 emissions on the ETS market has been very low in the last years (Figure 1.3). On the other hand the impact assessments that provide policy scenarios necessary to achieve the de-carbonization goals the EU sets itself consider much higher prices (ranged from 17 Euros per ton to 103 Euros per ton), and apply these prices not only to sectors already belonging to the ETS but to all the rest of the economy too (European Commission, 2011e). This inconsistency shows that the instruments put in place so far to curb emissions are not sufficient to achieve the targets of emissions reduction.

Figure 1.3. EU ETS: Average of daily closing price

Unit: euro per ton of CO_2.
Source: own elaboration from Sendeco data (Sendeco, 2015).

This context evidences the need to proceed in the search of a global consensus and a global commitment, and the need for more effective environmental policies to reduce emissions.

1.3. Aim, structure, and main contributions of this thesis

The evolution of atmospheric emissions, the difficulty and the need of implementing new policies to reduce emissions, and the role of the EU make up the frame of this thesis. There is an increasing number of scientific studies that seek to quantify and predict the possible effects and implications of climate change (IPCC, 2013), and they often conclude that these could be extremely serious. Despite this, the problem of atmospheric emissions that cause the rise in global temperatures has not yet found an effective solution. Although there are several policy instruments that could reduce the phenomenon of atmospheric emissions, neither the international community nor more regional entity like the EU have succeeded so far to translate their challenging objectives in incisive policies. The aim of the following thesis is to provide some empirical evidence to enrich the debate on the evolution of emissions causing climate change and on the policy instruments that could reduce atmospheric pollution.

This thesis is composed of four separate analyses related to emissions evolution and emissions reduction policies (Chapters 2 to 5). This section provides, first, an overview on each Chapter's content and structure (Section 1.3.1). Then, Section 1.3.2 concludes describing the thesis main contributions.

1.3.1. Chapters structure

Chapter 2 proposes a first approach to the issue of atmospheric pollution. In particular, it analyzes the evolution of two groups of gases for Italy in the years 1995-2005: GHG emissions and acidification emissions. Looking at data, while emissions that contribute to the local problem of acidification have been decreasing quite constantly, GHG emissions have been showing a slight increase. The aim is therefore to highlight how different economic factors have driven the evolution of Italian emissions. The main factors considered are changes in technology, changes in the volume and changes in the structure of final demand. The methodology proposed is a structural decomposition analysis (SDA), a method that permits to decompose changes of the variable of interest among different driving forces and to reveal the relevance of each factor. This first proposal, although empirical, faces a more methodological issue in order to take into account international trade for analyzing emissions. Indeed, as a contribution to the existing literature, this analysis considers the relevance of international trade. Through international trade a country could be exporting polluting production processes without a real reduction of the pollution implied in its production and consumption patterns. For this purpose, the SDA is firstly applied to the emissions actually generated in Italy. Successively, the decomposition is applied to the emissions Italy would have produced in absence of trade. In this way the exercise allows a first check of the importance of international trade and it highlights some results at global as well at sector level that can indicate in which direction further analysis should be carried on.

The following three chapters move on a more applied perspective, focusing on policies of emissions reduction and providing insights on their possible impact. In particular, Chapter 3 analyzes the European ETD reform proposed in 2011. This reform, proposed by the European Commission, tried to strengthen the effectiveness of the current European energy tax through higher rates on the use of energy products and less exemptions than the current directive. It was also aimed at coordinate this policy with the other economic instrument of emissions control implemented at European level, the ETS. Anyway, the proposal was not supported by the Parliament and finally it was not implemented. The analysis proposed in Chapter 3 shows what effect it would have, if implemented, on the level of prices in the different sectors of the 27 countries of the EU.[6] As far as we know, there are almost no studies on the potential economic implications of the 2011 ETD reform. Since the debate on a possible European carbon tax is still a current debate, we think it is important to provide empirical evidence on its possible effects. We apply a multi-regional and multi-sector model of trade flows that takes into account all the inter-sector and inter-country interdependences in the production processes. We perform two different simulations. The first one considers the tax changes proposed by the reform.

[6] We analyzed the EU27 countries due to data availability. These are the EU28 countries listed in note 4 except for Croatia.

The second one shows the impact the reform would have entailed if it were applied also to sectors belonging to the European ETS. The results of the simulations are a starting point to show if the reform would have implied a strong economic impact on costs and prices.

Chapter 4 proposes a similar analysis. Also this Chapter focuses indeed on the ETD reform, but it analyzes its effect only for one country, Italy. In fact for this country we obtained data on the use of energy products far more disaggregated and detailed then the ones used in Chapter 3. The dataset obtained is particularly relevant as it disaggregates data on energy products based on the purpose which they are used for. It distinguishes for example between gas used to heat and gas used in industrial processes. Since the energy tax and its reform apply different tax rates depending on the purpose energy products are used for, these data especially fits the scope of our analysis and they permit to avoid some approximations necessary in the previous Chapter. However, due to the fact that we have disaggregated data only for Italy, we carry out the analysis within a single-region framework. This framework assumes that products imported in a region have been produced using the same technology available in the region analyzed. This is an unrealistic assumption, but it makes the use of detailed data on energy products possible. The aim of this analysis is to compare the results obtained through a single-region model with the results obtained in Chapter 3. The comparison permits to verify if, in the case analyzed, a single-region model can be a good approximation of a more realistic multi-region model.

Finally, Chapter 5 analyzes a different policy instrument that is the so-called carbon-motivated border tax adjustment (CBTA). CBTA consists in tariffs applied to imported products. They are designed to avoid possible negative effects of emissions abatement policies when only one or few regions (the abating regions) implement them. In fact, emissions abatement policies applied only locally create a gap between the price of domestic and foreign products that finally compete in the same market. This different treatment could cause loss of competitiveness for domestic products and carbon leakage. CBTA is thought as a remedy. Through this instrument the abating regions level out different treatment applied to domestic and imported products (or in other words they level the carbon playing field). In particular we focus on CBTA metric, since tariffs can be computed differently depending on what emissions are considered as the tax base.

There are two main approaches. On the one hand, tariffs can be based on the emissions generated abroad in the non-abating regions. On the other hand, they can be based on the emissions contained in the same product if it were produced in the abating region. The debate revolves around the compatibility of the two metrics with the World Trade Organization rules. Through a multi-region and multi-sector analysis, in Chapter 5 we simulate what tariffs system should be applied to products imported by the EU27 to compensate a hypothetical European CO_2 emissions taxation, comparing the two different metrics. To know for which countries and sectors the method used is critical can help to add information to the political debate. An important contribution of this analysis is that we explore methodological issues that arise from the use of multi-region and multi-sector models to compute different CBTA metrics.

In each Chapter, after an introduction, we describe methodology, database, results, and conclusion of each analysis Moreover, each Chapter has a Section with the references quoted in the text. At the end of the thesis the bibliography also provides the full list of articles and sources used, although the quotations refer to the Chapters' references list. Each Chapter has also a Section of appendices with additional information that might complement the one provided in the main text. In some cases, due to the big amount of results obtained, we selected the information shown to make its interpretation easier. Anyway, any further material not inserted is available under request. Since we used two main databases in the four analyses proposed, each Chapter describes specifically the data used, while the thesis Annex A provides a more detailed description of the two databases and a comparison. . For ease of reading, the acronyms used are defined in each Chapter (see the thesis Annex B for a complete list of acronyms and chemical symbols).

Previous versions of the analyses proposed in this thesis have been presented in national and international conferences. Chapter 2 was presented to the IV Spanish Conference on Input-Output Analysis (Madrid, 2011) and to the I Conferencia de la Asociación de Economía Ecológica en España (Barcelona, 2011). Chapter 3 was presented to the XVI Encuentro de Economía Aplicada (Granada, 2013), to the V Conference on Input-Output Analysis (Sevilla, 2013), and to the XXI International Input-Output Conference (Kitakyushu, 2013). Chapter 5 was presented to the XXII International Input-Output Conference (México D.F., 2015), to the XI

Biennial Conference of the European Society for Ecological Economics (Leeds, 2015), and to the VI Spanish Conference on Input-Output Analysis (Barcelona, 2015). Moreover, some results have been published. Chapter 2, a previous version of Chapter 3, and Chapter 5 were published in the collection of working papers in Economics of the University of Barcelona (E11/267, E13/295, and E15/327 respectively). Chapter 3 was published in 2014 in Energy Policy (75).

1.3.2. Thesis main contributions

Besides the new empirical evidence that each analysis shows, the following thesis has two main contributions. A first contribution is the use of a relatively recent database, the World Input-Output Database (WIOD). Since 2012, the WIOD project made available a public database with time-series of input-output tables for 40 countries worldwide. These tables have been constructed using input-output tables in conjunction with national accounts and international trade statistics. In this way they are able to keep track of the complex production processes that are increasingly fragmented across borders. In particular we used the WIOD database in two of the analyses proposed (Chapters 3 and 5). In fact one of the main advantages of this multi-region database is that it also records data about energy use and air emissions, with the same sector breakdown and geographical coverage as the input-output tables. This accurate description of all inter-industry inter-country interconnections and of environmental accounts offers a useful and reliable instrument to analyze emissions and emissions reduction policies.

The second contribution is that we use this multi-country multi-sector database to bring new information to light and to provide guidance to implement policies of emissions abatement. In fact, on the one hand big emitters such as China or the US are expressing the will to make important steps towards a less carbon intensive development with measures such as investments in renewable energies, or attempts to reduce the use of coal (Burk et al., 2014). The private sector is also taking a stand in this issue. Even large private businesses of the energy sector – such as some European oil and gas companies – lately expressed support to emissions abatement policies, calling for a tax on carbon emissions.[7]

[7] This information refers to the article "The case for a carbon tax" written by the editorial board of The New York Time on June, sixth, 2015 (available at

On the other hand, an international agreement to set new targets for reducing emissions has not yet been achieved. In the same way there are no policies for emissions abatement applied at global or international scale. Institutions such as the EU recognize that many countries still need additional efforts to meet their 2020 targets. Moreover these targets are not a guarantee for limiting the rise of global temperature.

New policies therefore continue to be necessary to address the risks associated with global climate change. The need for more tools to reduce emissions leads to the consequent need for more analyses for understanding the possible effects of these policies. This thesis seeks to provide a marginal contribution in this direction.

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Chapter 2

Environmental Structural Decomposition Analysis of Italian Emissions, 1995-2005

2.1. Introduction[8]

Atmospheric pollution is one of the pressures that human activities exert on the environment. Some of the gases released into the atmosphere are causing local and regional damages such as acid rain or acidification. Other contaminants might have a more global effect mainly contributing to climate change, such as greenhouse gases (GHGs).

Over time, each country has contributed differently to the amount of gases present in the atmosphere. As regards Italy, a first glance at data on Italian emissions shows a peculiar characteristic (Figure 2.1). On the one hand, since 1990 emissions that contribute to acidification have been decreasing quite constantly. On the other hand GHG emissions showed a slight increase until 2005. In fact, data of the International Energy Agency[9]

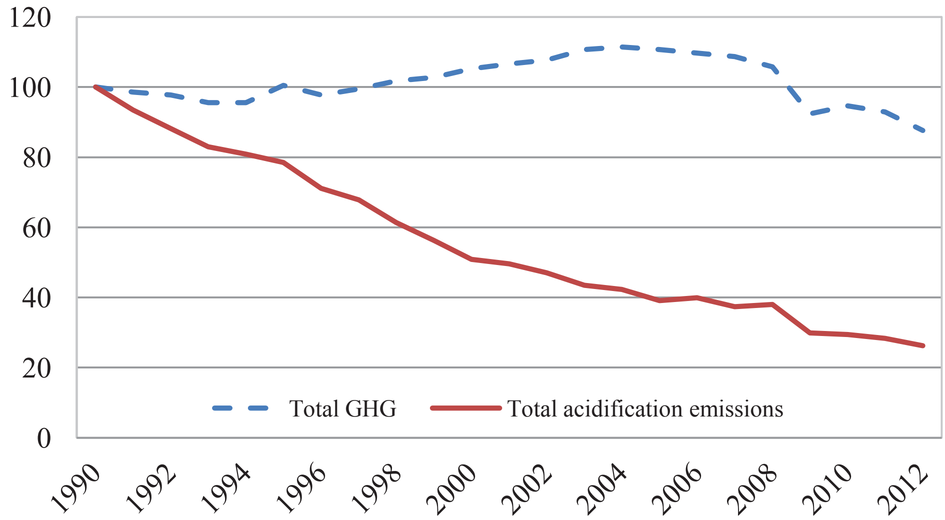
[8] A previous version of this Chapter was originally published as working paper in UB Col·lecció d'Economia (2011), E11/267. It was presented to the IV Spanish Conference of Input-Output Analysis (Madrid, 2011) and to the I Conferencia de la Asociación de Economía Ecológica en España (Barcelona, 2011). I thank the participants for useful comments that help to improve this work.

[9] Available at: http://www.eia.gov/countries/data.cfm

reveals that Italian emissions of carbon dioxide (CO_2), the main GHG, accounted for the 1.92% of the world's total emissions in 1990, and for the 1.66% in 2005, ranking Italy among the world's ten largest CO_2 emitters.

Within this framework, the following research analyzes the different evolution of these two groups of gases for Italy and their driving forces. We analyze the period 1995-2005, considering the years before the economic crisis that took place since 2008/2009.[10] The emissions analyzed are the three main GHGs – CO_2, nitrous oxide (N_2O), and methane (CH_4) – and three gases related to local environmental problems: nitrogen oxides (NO_X), sulfur oxides (SO_X), and ammonia (NH_3). In particular, the study analyzes the role that different forces had in causing such a different trend. Generally, changes in emissions are mainly affected by changes in production technologies, in the volume of final demand or in its composition. These are the three factors considered in the study.

Figure 2.1. Evolution of Italian atmospheric emissions



Unit: 1990 emissions base=100.
Source: own elaboration from ISTAT data (ISTAT, 2010b).

To analyze the evolution of GHG and acidification emissions, we will perform a structural decomposition analysis (SDA). This method permits to decompose the changes of the variable of interest among different driving forces and to reveal the relevance of each factor. The knowledge of the role

[10] Some authors have found that the emission reduction after 2008 was facilitated to some extent by the economic crisis (Haita, 2012).

of different determinants is helpful to figure out effective political instruments that would permit to reduce environmental pressures.

Moreover, the analysis considers also international trade. In fact, changes in trade flows might influence the evolution of emissions. Not consider international trade could distort the results of the analysis. If for example data show a decrease of the Italian emissions, the analysis might conclude that the country has developed more environment-friendly ways of production. However, part of the inputs used to produce goods and part of domestic final demand are imported from abroad. Then, a decrease of emissions could be due to the fact that the country is simply importing more of the polluting products from abroad, such that emissions actually released by the country decrease, but without a real improvement of the production process. Similarly, some goods produced domestically are exported, and an increase of emissions might be due to more exports.

Due to the Italian balance trade structure, it seems relevant to consider international trade in the analysis of Italian emissions. In fact, the existence of little natural endowment makes international trade a key element for Italian growth, which depends on a systematic current account deficit. Moreover, as Viviani (2010) highlights, Italy has a substantially energy-intensive manufacturing base. Tables 2.1 and 2.2 show data data on CO_2 emissions for the five most polluting sectors and on import and export flows for the five most relevant sectors as regards the Italian current account balance (for the year 1995). It is worth noticing that some of the most polluting sectors are also among the relevant sectors for international trade.

Table 1.1. CO_2 emissions for the five most polluting sectors

	1995	**2000**	**2005**	**Variation (95-05)**
Electricity, gas and water supply	114708.52	122674.76	135359.58	18%
Manufacture of other non-metallic mineral products	37774.94	43324.31	45258.93	20%
Manufacture of basic metals	24053.09	19591.33	18901.74	-21%
Manufacture of coke, refined petroleum products	23145.84	22915.96	24259.08	5%
Wholesale and retail trade; repair of motor vehicle	21501.67	18765.19	19415.57	-10%

Unit: thousands of tons.

Source: own elaboration from ISTAT data (ISTAT, 2010b).

Table 2.2. Export and Import for the five most trade-relevant sectors

Export				
	1995	**2000**	**2005**	**Variation (95-05)**
Manufacture of machinery and equipment	37795.41	49505.69	58705.24	55%
Manufacture of chemicals	15090.98	23448.94	29170.27	93%
Manufacture of motor vehicles	14696.45	19000.31	21026.21	43%
Wholesale and retail trade; repair of motor vehicle *	13267.92	18251.42	19850.67	50%
Textiles	12359.66	14634.45	12897.91	4%
Import				
	1995	**2000**	**2005**	**Variation (95-05)**
Manufacture of chemicals	24056.68	33452.06	41990.21	75%
Manufacture of basic metals*	18816.35	22333.08	27626.01	47%
Manufacture of motor vehicles	16198.96	28260.67	35462.67	119%
Manufacture of food products, beverages, tobacco	14401.27	15942.68	19309.23	34%
Manufacture of machinery and equipment	13195.96	20473.80	22162.20	68%

Unit: millions of euro.
*: Relevant sectors for CO_2 emissions.
Source: own elaboration from ISTAT data (ISTAT, 2010a).

In literature there are many studies that analyze the evolution of emissions through a SDA taking into account international trade. They follow two main approaches. Some papers consider trade as one of the driving forces that influence the emissions evolution (Chen and Wu, 1994; Jacobsen, 2000; de Haan, 2001; Wilting et al., 2006; Peters et al., 2007; Wu et al., 2007; Guan et al., 2008; Lim et al., 2009; Baiocchi and Minx, 2010; Arto and Dietzenbacher, 2014). Although results change depending on the countries and years analyzed, they generally find that import and export often offset each other in influencing emissions, and international trade is not the main driving of emissions changes. More recently, another strand of literature proposes a different approach, focusing directly on the emissions embodied in trade flows (Yamakawa and Peters, 2001; Yunfeng and Laike, 2010; Du et al., 2011; Edens et al., 2011; Minx et al., 2011; Xu et al., 2011; Su et al., 2013; Xu and Dietzenbacher, 2014). This approach permits to compute the emissions balance of a country, introducing the problem of responsibility: the responsibility for emissions entailed in trade flows could be assigned to countries that are actually producing them or to countries whose consumption makes the emissions necessary. A common finding of these papers is that developed countries are shifting the responsibility for their consumption abroad through trade.

As regards the Italian case, few studies propose the analysis of atmospheric emissions using a SDA (Alcantara and Duarte, 2004;

Campanale, 2007; Mazzanti and Montini, 2009; Cellura et al., 2012). However, none of these studies consider international trade. The only paper that analyzes the evolution of Italian GHG emissions considering trade is Campanale and Femia (2012). In particular, to take trade into account they analyze total emissions including also the pollution that Italy would have emitted if it produced domestically all the goods imported. They compute a SDA on the total emissions of CO_2, N_2O, and CH_4 for the period 1999-2007. They decompose the emissions change in four driving forces: emissions intensity, technology, final demand volume, and final demand structure. As Cellura et al. (2012), they find that emissions intensity would have caused emissions to decrease, but that the increase of final demand nullified it. Computing then the emissions avoided through import they conclude that actual domestic GHG emissions from production would have grown much more if there had been no displacement of production abroad.

Complementing the approaches described before, in this work we propose an alternative way to take into account trade. In particular we propose a comparison of two different SDAs. The first decomposition is applied to the territorial emissions caused by domestic production, which includes domestic production for domestic demand and for exports while it does not consider imports. Successively, the analysis asks what would have been the role of technology and final demand apart from international trade. So, instead of decomposing territorial emissions, a second SDA decomposes the amount of emissions Italy would have produced in absence of trade. In this scenario we assume that Italy produces domestically all the inputs it actually uses, as well as the final demand usually satisfied through imports. Meanwhile, however, the emissions attributed to exports are excluded. This counterfactual analysis permits a first check of the importance of international trade in the evolution of Italian emissions and it highlights some results at global as well at sector level that can indicate in which direction further analysis should be carried on.

In the following Sections we describe methodology (Section 2.2) and data description (Section 2.3). Section 2.4 shows the main results, and Section 2.5 concludes.

2.2. Methodology

In this study we follow the single-region input-output model used by Serrano and Roca (2008) in which trade relationships between a small open country and the rest of the world are considered. Considering trade flows, the model permits to include the emissions related to imports in the analysis. Anyway, it does not assess the actual pollution that foreign countries emit to produce the imported products, as a multi-regional model does. Instead, it focuses on the emissions that a country is avoiding through import. Assuming that the country could be self-sufficient and acts as an autarchy, the single-region input-output model applies the so-called "domestic technology assumption" (DTA), and it computes the emissions the country would have generated producing the imported goods with the technology available domestically, as a closed economy.

The small open economy is represented by the following expressions:[11]

$$\mathbf{x} = (\mathbf{I} - \mathbf{A_d})^{-1}(\mathbf{y_d} + \mathbf{ex}) \tag{2.1}$$

$$\mathbf{im} = \mathbf{A_{im}}\mathbf{x} + \mathbf{y_{im}} \tag{2.2}$$

Where $\mathbf{x}$ is domestic gross output, $\mathbf{I}$ is the identity matrix, $\mathbf{A_d}$ is the matrix of domestic input coefficients, $\mathbf{y_d}$ is domestic final demand (that comprises domestic private consumption by household, domestic public consumption by government, and domestic investment), and $\mathbf{ex}$ are exports. Expression (2.2) shows the required total imports $\mathbf{im}$ of this economy, no matter if they are used as intermediate inputs $\mathbf{A_{im}x}$ or as final demand $\mathbf{y_{im}}$.[12]

[11] Matrices are indicated by bold, upright capital letters; vectors by bold, upright lower case letters; and scalars by italicized lower case letters. Vectors are columns by definition, so that row vectors are obtained by transposition, indicated by a prime. A circumflex indicates a diagonal matrix with the elements of any vector on its diagonal and all other entries equal to zero. The notation $\mathbf{i}$ is used to represent a column vector of 1's of appropriate dimensions.

[12] Matrices of domestic input coefficients $\mathbf{A_d}$ and imported input coefficients $\mathbf{A_{im}}$ are defined as $\mathbf{A_d} = \mathbf{Z_d}(\hat{\mathbf{x}})^{-1}$ and $\mathbf{A_{im}} = \mathbf{Z_{im}}(\hat{\mathbf{x}})^{-1}$, respectively; where $\mathbf{Z_d}$ and $\mathbf{Z_{im}}$ are the intermediate inter-industry deliveries matrices. $\mathbf{Z_d}$ gives the deliveries from sector *i* to sector *j* within the country, and $\mathbf{Z_{im}}$ gives the deliveries from the rest of the world's sector *i* to the country's sector *j*.

The technology of an open economy is determined by the matrix of total input coefficients $\mathbf{A_t}$, given by $\mathbf{A_t} = \mathbf{A_d} + \mathbf{A_{im}}$. Since total supply should equal total demand, the equilibrium of this economy is given by:

$$\mathbf{x} + \mathbf{im} = \mathbf{A_t x} + \mathbf{y_t} \tag{2.3}$$

Pre-multiplying the right side of equation (2.1) by the diagonal matrix $\hat{\mathbf{e}}$ of emission coefficients of any pollutant,[13] we can obtain the domestic emissions $\mathbf{e_D}$ as:

$$\mathbf{e_D} = \hat{\mathbf{e}}(\mathbf{I} - \mathbf{A_d})^{-1}(\mathbf{y_d} + \mathbf{ex}) \tag{2.4}$$

We will refer to the emissions vector $\mathbf{e_D}$ as territorial emissions.

On the other hand, the emissions a country would produce in absence of trade would be:

$$\mathbf{e_A} = \hat{\mathbf{e}}(\mathbf{I} - \mathbf{A_t})^{-1}(\mathbf{y_d} + \mathbf{y_{im}}) \tag{2.5}$$

We will refer to the emissions vector $\mathbf{e_A}$ as the emissions without trade.

Expression (2.4) can be simplified in the following way:

$$\mathbf{e_D} = \mathbf{Fy} = \mathbf{F}[\mathbf{y}/\mathbf{i}'\mathbf{y}][\mathbf{i}'\mathbf{y}] = \mathbf{F}\mathbf{y_s}\mathbf{y_v} \tag{2.6}$$

Where $\mathbf{F}$ is the emissions multiplier $\mathbf{F} = \hat{\mathbf{e}}(\mathbf{I} - \mathbf{A_d})^{-1}$ and $\mathbf{y}$ is the summation of domestic final demand and export $\mathbf{y} = \mathbf{y_d} + \mathbf{ex}$. In expression (2.6) $\mathbf{y}$ is divided into a structure component ($\mathbf{y_s}$) and a volume component ($\mathbf{y_v}$).

Similarly for expression (2.5) we have:

$$\mathbf{e_A} = \tilde{\mathbf{F}}\tilde{\mathbf{y}} = \tilde{\mathbf{F}}[\tilde{\mathbf{y}}/\mathbf{i}'\tilde{\mathbf{y}}][\mathbf{i}'\tilde{\mathbf{y}}] = \tilde{\mathbf{F}}\tilde{\mathbf{y}}_s\tilde{\mathbf{y}}_v \tag{2.7}$$

[13] The vector $\mathbf{e}$ is equal to total sector's emissions over total sector's production.

Where $\tilde{\mathbf{F}}$ is the emissions multiplier $\tilde{\mathbf{F}} = \hat{\mathbf{e}}(\mathbf{I} - \mathbf{A_t})^{-1}$, $\tilde{\mathbf{y}}$ is the total domestic final demand $\tilde{\mathbf{y}} = \mathbf{y_d} + \mathbf{y_{im}}$ and $\tilde{\mathbf{y}}_s$ and $\tilde{\mathbf{y}}_v$ are the structure and volume components of the domestic final demand, respectively.

Once we obtain territorial emissions and emissions without trade decomposed in their different driving forces, we apply a SDA to show how these determinants changed over time.

Considering territorial emissions first, the decomposition applied is:

$$\Delta\mathbf{e_D} = \mathbf{e_D^1} - \mathbf{e_D^0} = \mathbf{F^1 y_s^1 y_v^1} - \mathbf{F^0 y_s^0 y_v^0} = \mathbf{ef\_F} + \mathbf{ef\_y_s} + \mathbf{ef\_y_v} \tag{2.8}$$

Where ef_F captures the joint effect of the vector of direct emissions coefficients $\mathbf{e}$ and the matrix $(\mathbf{I} - \mathbf{A_t})^{-1}$ and it can be considered as the eco-technological effect, $\mathbf{ef\_y_s}$ represents the variation in the final demand structure while $\mathbf{ef\_y_v}$ captures the effect of variations in the final demand volume.

Among the several decomposition techniques, this study applies the methodology proposed by Sun (1998), who suggests to calculate the decomposition using the Laspeyres index and to distribute the residual term in equal part among the different factors.[14] This decomposition leads to a complete decomposition without a residual term. In the case of territorial emissions the method proposed by Sun takes the following form:

$$\begin{cases} \mathbf{ef\_F} = (\Delta\mathbf{F y_s^0 y_v^0}) + \mathbf{1/2}\,(\Delta\mathbf{F}\Delta\mathbf{y_s y_v^0}) + \mathbf{1/2}\,(\Delta\mathbf{F y_s^0}\Delta\mathbf{y_v}) + \mathbf{1/3}\,(\Delta\mathbf{F}\Delta\mathbf{y_s}\Delta\mathbf{y_v}) \\ \mathbf{ef\_y_s} = (\mathbf{F^0}\Delta\mathbf{y_s y_v^0}) + \mathbf{1/2}\,(\Delta\mathbf{F}\Delta\mathbf{y_s y_v^0}) + \mathbf{1/2}\,(\mathbf{F^0}\Delta\mathbf{y_s}\Delta\mathbf{y_v}) + \mathbf{1/3}\,(\Delta\mathbf{F}\Delta\mathbf{y_s}\Delta\mathbf{y_v}) \\ \mathbf{ef\_y_v} = (\mathbf{F^0 y_s^0}\Delta\mathbf{y_v}) + \mathbf{1/2}\,(\Delta\mathbf{F y_s^0}\Delta\mathbf{y_v}) + \mathbf{1/2}\,(\mathbf{F^0}\Delta\mathbf{y_s}\Delta\mathbf{y_v}) + \mathbf{1/3}\,(\Delta\mathbf{F}\Delta\mathbf{y_s}\Delta\mathbf{y_v}) \end{cases} \tag{2.9}$$

For emissions without trade we have similar expressions. The decomposition applied is:

$$\Delta\mathbf{e_A} = \mathbf{e_A^1} - \mathbf{e_A^0} = \tilde{\mathbf{F}}^1 \tilde{\mathbf{y}}_s^1 \tilde{\mathbf{y}}_v^1 - \tilde{\mathbf{F}}^0 \tilde{\mathbf{y}}_s^0 \tilde{\mathbf{y}}_v^0 = \mathbf{ef\_}\tilde{\mathbf{F}} + \mathbf{ef\_}\tilde{\mathbf{y}}_s + \mathbf{ef\_}\tilde{\mathbf{y}}_v \tag{2.10}$$

The variation of the three driving forces is computed as:

[14] It is possible to show that this solution is equal to the mean of the (n!) possible decomposition forms proposed by Dietzenbacher and Los (1998).

$$\begin{cases} \mathbf{ef\_\tilde{F}} = \left(\Delta\tilde{\mathbf{F}}\tilde{\mathbf{y}}_s^0\tilde{\mathbf{y}}_v^0\right) + \mathbf{1/2}\left(\Delta\tilde{\mathbf{F}}\Delta\tilde{\mathbf{y}}_s\tilde{\mathbf{y}}_v^0\right) + \mathbf{1/2}\left(\Delta\tilde{\mathbf{F}}\tilde{\mathbf{y}}_s^0\Delta\tilde{\mathbf{y}}_v\right) + \mathbf{1/3}\left(\Delta\tilde{\mathbf{F}}\Delta\tilde{\mathbf{y}}_s\Delta\tilde{\mathbf{y}}_v\right) \\ \mathbf{ef\_\tilde{y}_s} = \left(\tilde{\mathbf{F}}^0\Delta\tilde{\mathbf{y}}_s\tilde{\mathbf{y}}_v^0\right) + \mathbf{1/2}\left(\Delta\tilde{\mathbf{F}}\Delta\tilde{\mathbf{y}}_s\tilde{\mathbf{y}}_v^0\right) + \mathbf{1/2}\left(\tilde{\mathbf{F}}^0\Delta\tilde{\mathbf{y}}_s\Delta\tilde{\mathbf{y}}_v\right) + \mathbf{1/3}\left(\Delta\tilde{\mathbf{F}}\Delta\tilde{\mathbf{y}}_s\Delta\tilde{\mathbf{y}}_v\right) \\ \mathbf{ef\_\tilde{y}_v} = \left(\tilde{\mathbf{F}}^0\tilde{\mathbf{y}}_s^0\Delta\tilde{\mathbf{y}}_v\right) + \mathbf{1/2}\left(\Delta\tilde{\mathbf{F}}\tilde{\mathbf{y}}_s^0\Delta\tilde{\mathbf{y}}_v\right) + \mathbf{1/2}\left(\tilde{\mathbf{F}}^0\Delta\tilde{\mathbf{y}}_s\Delta\tilde{\mathbf{y}}_v\right) + \mathbf{1/3}\left(\Delta\tilde{\mathbf{F}}\Delta\tilde{\mathbf{y}}_s\Delta\tilde{\mathbf{y}}_v\right) \end{cases} \tag{2.11}$$

2.3. Data description

The main databases used are the input-output tables from the Italian System of National Accounts and data on emissions from the Italian Environmental Satellite Accounts of Air Emissions.

As regards input-output tables, this study uses the “commodity-by-commodity” input-output tables (IOT) made available by the Italian National Statistical Institute (ISTAT) (ISTAT, 2010a).[15] In the input-output series used,[16] tables are available for the years 1995, 2000, and 2005 and data are expressed at basic current prices.[17] For a comparison among different years, input-output tables should be considered in constant prices. Taking into account the available data, we have estimated the 1995 and 2005 SIOTs at 2000 constant prices applying the double-deflation method. The dimension of the three IOT at constant prices is 38x38 (see appendix 2.A for a sectors’ complete list).

As regards data on air emissions, since February 2010 National Accounting Matrix including Environmental Accounts (NAMEA) tables have been available for Italy (ISTAT, 2010b) for the period 1990-2008.[18] The analysis considers three GHG gases (CO_2, N_2O, CH_4) and three acidification gases (NO_X, SO_X, NH_3). Moreover, two indices are included. For a synthetic measure of greenhouse effect, GHG gases are converted into

[15] See the thesis Annex A for a detailed description of ISTAT input-output tables system and ISTAT Environmental Satellite Accounts.
[16] This analysis was done before 2013, when data on Italian atmospheric emissions were available until 2008. In 2013 an update version of the same database has been published and tables are now available also for the year 2010. An interesting extension of this work is indeed to enlarge its time scope.
[17] Input-output tables have been estimated from supply and use tables for the years 1995, 2000 and 2005. Though results are similar to data made available by ISTAT, input-output tables used for the SDA are the one proposed by ISTAT because they are obtained from supply and use tables with a higher level of desegregation (101 industries instead of 59).
[18] Nineteen atmospheric pollutants are reported in physical units. In tons: carbon dioxide, nitrous oxide, methane, nitrogen oxides, sulphur oxides, ammonia, composed organic volatile not methanic, carbon monoxide, particulate PM10, particulate PM25. In kilograms: arsenic, cadmium, chrome, copper, mercury, nickel, lead, selenium and zinc.

CO_2-equivalent units using the Global Warming Potential (GWP).[19] Similarly, for acidifying effect, acidification gases are converted on the base of their Potential Acid Equivalent (PAE).[20] NAMEA data on emissions have the same structure of supply and use tables where secondary production is considered. They indeed need to be transformed following the same structure as a “commodity-by-commodity” IOT, where the secondary production is re-assigned under the “industry technology” hypothesis, assuming that each industry has its own specific technical process, used to produce any product. Hence, in this study data on emissions are estimated under the same assumption for 1995, 2000 and 2005.

2.4. Results

In this section we present the SDA results for the periods 1995-2000 and 2000-2005. The analysis of two different sub-periods makes it possible to highlight that the relevance of the considered factors changed over time. Results for the whole economy are shown in section 2.4.1, whereas section 2.4.2 analyzes the sector-based results.

2.4.1. SDA for the economy

Tables 2.3 and 2.4 show the decomposition of the variation of territorial emissions in Italy. Table 2.3 considers GHG emissions and the GHG index (GHGeq), showing in columns 2 to 5 the variation for the period 1995-2000, and in columns 6 to 9 the variation for the period 2000-2005. Similarly, Table 2.4 shows the decomposition of emissions related to acidification gases and the acidification index (Acid) in the two sub-periods considered.

The main trends are common for both groups of gases, and are in line with the main finding of the literature reviewed before. One the one hand the eco-technological effect would have brought emissions to decrease in both periods, but the increase in the volume of final demand boosted an increase in emissions, offsetting – sometimes totally sometimes partially – the effect of eco-technology. In general the final use structure effect caused

[19] Conversion factors to CO_2- equivalent: $CO_2 = 1$; $N_2O = 310$; $CH_4 = 21$ (EPA, 2004).
[20] Conversion factors to PAE: $SO_X = 1/32$; $NO_X = 1/46$; $NH_3 = 1/17$ (EPA, 2004).

emissions to increase in the first period while improved in the second period, but in both cases this effect is less relevant than the other two.

Looking at GHG emissions (Table 2.3), CO_2 is the gas that increases most. In the first sub-period this is due to an intense increase in the volume of final demand and to a worsened consumption structure, although an important eco-technological improvement avoids stronger emissions increases. The overall CO_2 trend worsens in the second sub-period, when emissions increase by 5.8%: although the increase in final use volume is less strong, in this case also eco-technological component causes emissions to increase. As regards the other GHG emissions, in the first period there is an increase in N_2O emissions: technological improvement is not strong enough to compensate final use structure and volume effects. For CH_4 emissions, the analysis reveals, in the first period, a global variation near to zero due to an offset between the eco-technological effect and the final use level. An interesting result is that for both N_2O and CH_4, the better performance that characterizes the second sub-period is not due to a better eco-technology. It is instead due to a cleaner demand structure and to a final use volume that increases relatively less.

The GHG index has the same trends as CO_2 emissions, although the eco-technological change in the second period has a negative sign thanks to N_2O and CH_4 technological improvement. Nonetheless, in both periods the total change of GHG index is an increase of emissions, more relevant in the second period.

Table 2.2. SDA for GHG emissions and GHG index, territorial emissions

	1995-2000				2000-2005			
	CO_2	N_2O	CH_4	GHGeq	CO_2	N_2O	CH_4	GHGeq
Eco-technology (ef_F/e_D^0)	-11.18	-11.22	-12.16	-11.28	2.06	-8.26	-13.49	-0.34
Final use structure (ef_y_s/e_D^0)	2.03	2.69	1.35	2.02	-0.59	0.76	-0.74	-0.49
Final use level (ef_y_v/e_D^0)	10.97	10.99	10.88	10.96	4.35	4.15	4.01	4.30
Total effect* ($\Delta e_D/e_D^0$)	1.83	2.47	0.06	1.71	5.82	-3.34	-10.22	3.47

Unit: percentage.

*: The sum does not perfectly fit because of decimal approximations.

Source: own elaboration from ISTAT data (ISTAT 2010a, 2010b).

As regards acidifying gases NO_X, SO_X, and NH_3 (Table 2.4), the general decrease of emissions level during the years 1995-2000 is mainly due to a strong technological improvement, in particular for NO_X (-35%) and SO_X (-55%), only partially offset by a positive final use volume variation (close to 10%) and a positive but very small final use structure variation (between 0.8% and 3.5%). In the years 2000-2005 the decrease of emissions continues to be very important in the case of SO_X (-47.5%). Also in this case, the driving factor is a strong eco-technological improvement. The decrease of NO_X emissions is a quarter of the decrease of the first period, due to a downfall in technological improvement. The decrease of NH_3 emissions is higher in the second period. Also in this case it is not due to a further technological improvement (eco-technological effect is actually less relevant during the years 2000-2005). It is due to the decrease of the positive final use level effect variation and to the variation of final use structure effect that in the second period becomes negative.

Table 2.3. SDA for acidification emissions and acidification index, territorial emissions

	1995-2000				2000-2005			
	NO_X	**SO_X**	**NH_3**	**Acid**	**NO_X**	**SO_X**	**NH_3**	**Acid**
Eco-technology (ef_F/e_D^0)	-35.02	-55.20	-15.26	-38.12	-11.74	-47.14	-10.30	-22.57
Final use structure (ef_y_s/e_D^0)	0.90	3.45	1.32	2.06	-0.90	-2.54	-1.39	-1.60
Final use level (ef_y_v/e_D^0)	9.62	8.70	10.70	9.53	4.05	3.27	4.06	3.80
Total effect* ($\Delta e_D/e_D^0$)	-24.50	-43.05	-3.24	-26.53	-8.60	-46.40	-7.63	-20.37

Unit: percentage.

*: The sum does not perfectly fit because of decimal approximations.

Source: own elaboration from ISTAT data (ISTAT 2010a, 2010b).

In conclusion, the main difference between the two groups of gases seems to be a stronger eco-technological improvement in the case of acidification emissions, although in both cases these improvements in technological processes are more effective in the first sub-period. These results are in line with a more general finding of the literature on the environmental Kuznets curve. Some local air contaminants, particularly SO_X, tend to decrease in rich countries when income per capita increases. This does not normally happen with global contaminants, and in particular with CO_2. Two are the main reasons. First, it is easier to implement end-of-pipe technologies for local emissions. Second, there is a strong incentive for emissions reduction in the case of local pollution because the negative effects of it fall back mainly on the country's inhabitants (Roca and Padilla, 2001).

The results described so far refer to territorial emissions that are the air pollutants actually emitted by Italy. As described before, we propose a second decomposition considering instead the emissions Italy would have produced without international trade. Tables 2.5 and 2.6 show the results of SDA applied to the emissions without trade, for GHG and acidification emissions respectively.

In general, the two different SDA reveal common trends, but some differences in results are worth noticing. Analyzing the emissions without trade, in particular for GHGs, the eco-technological effect is less effective in reducing emissions: if Italy produced all imports domestically to satisfy only the domestic final demand, the emissions reduction due to technological improvement would have been lower. Anyway, looking at the economy as a whole this difference is not substantial, and it is compensated by a better final demand structure: the composition of imported final products has less environmental impact than the export composition. The weight of final use volume is roughly the same if we exclude export and we include imported final goods. Differences in results between the two SDA are more significant for GHG emissions than for acidification emissions. As regards CO_2 emissions, in both periods the increase of emissions is stronger if we consider territorial emissions, mainly due to a less effective eco-technological effect, only partially compensated by a better evolution of final use structure in the second period. As regards N_2O emissions, though in the first period the two different SDA give similar results, the different factors have different weights: for emissions without trade the eco-technological improvement is less strong while the final use structure effect seems to be better. Also in the second period technological improvement is less relevant. The case of CH_4 emissions is the one where results more strongly differ between the two SDA. The technological improvement is less relevant looking at emissions without trade, and although in the second period the structure of final use seems better, the final result is a positive variation of emissions in the first period and a less important emission reduction in the second period. For acidification emissions differences between the two different SDA are not relevant. Only in the second period for NO_X and NH_3 emissions without trade reveals a worse variation of technology, while it reveals a better structure of final use for SO_X.

Table 2.4. SDA for GHG emissions and GHG index, emissions without trade

	1995-2000				2000-2005			
	CO_2	N_2O	CH_4	GHGeq	CO_2	N_2O	CH_4	GHGeq
Eco-technology (ef_F/e_D^0)	-9.87	-9.49	-8.25	-9.64	4.32	-5.43	-7.05	2.09
Final use structure (ef_y_s/e_D^0)	2.25	0.56	1.69	2.02	-1.81	-0.44	-3.83	-1.92
Final use level (ef_y_v/e_D^0)	11.23	11.15	11.28	11.23	4.26	4.08	3.98	4.21
Total effect* ($\Delta e_D/e_D^0$)	3.61	2.22	4.71	3.61	6.76	-1.79	-6.90	4.38

Unit: percentage.

*: The sum does not perfectly fit because of decimal approximations.

Source: own elaboration from ISTAT data (ISTAT 2010a, 2010b).

Table 2.5. SDA for acidification emissions and acidification index, emissions without trade

	1995-2000				2000-2005			
	NO_X	SO_X	NH_3	Acid	NO_X	SO_X	NH_3	Acid
Eco-technology (ef_F/e_D^0)	-34.54	-54.90	-15.24	-37.10	-10.73	-47.33	-9.37	-21.54
Final use structure (ef_y_s/e_D^0)	1.25	2.73	0.09	1.51	-1.13	-3.50	-1.52	-2.01
Final use level (ef_y_v/e_D^0)	9.82	8.81	10.80	9.70	3.96	3.16	3.97	3.72
Total effect* ($\Delta e_D/e_D^0$)	-23.47	-43.36	-4.34	-25.89	-7.90	-47.67	-6.92	-19.83

Unit: percentage.

*: The sum does not perfectly fit because of decimal approximations.

Source: own elaboration from ISTAT data (ISTAT 2010a, 2010b).

Anyway, in general, international trade does not seem to have played an important role in the evolution of emissions in Italy.

2.4.2. Sector-based results

The analysis of the results at a sector-based level (Figures 2.2 to 2.5) can enrich the information found so far in two different ways. First, it permits to find some explanations to the trends that the analyses at a global level have underlined. Second, it can help to highlight some sectors' peculiarities that could remain hidden in the global analysis.

For the two sub-periods considered Figures 2.2 and 2.3 show the results of SDA at sector level[21] for GHG emissions index, and Figures 2.4 and 2.5 for acidification emissions index. Sectors are ordered according to the absolute level of emissions in the base year. [22]

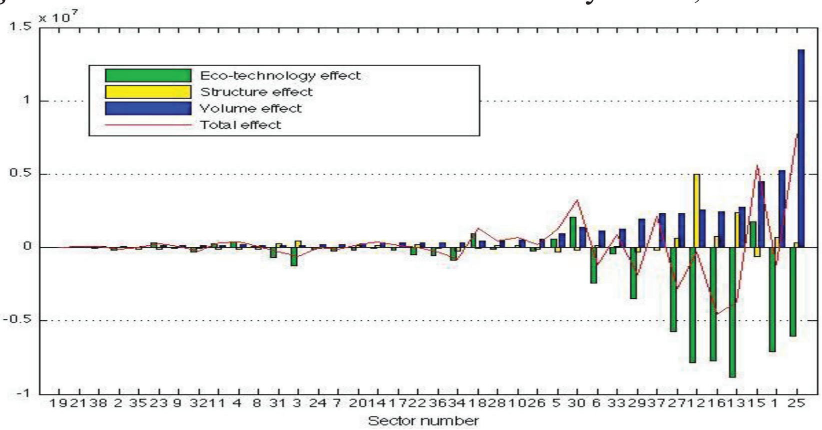
[21] For the correspondence between numbers and NACE sectors, see appendix 2.A.

[22] Appendix 2.B shows graphic results for all the gases analyzed .

As regards GHG emissions, in case of CO_2 the main responsible for emissions increase is “electricity sector” (25),[23] in the first sub-period due to an important effect of final use volume, in the second sub-period due to a worsening eco-technological effect and a worsening final use structure.

Moreover, while in the first sub-period there are three sectors that help emissions to decrease through an important eco-technological improvement – manufacture of chemicals” (13), “manufacture of basic metals” (16), and “wholesale and retail trade’” (27) – their relevance and their eco-technological performance gets worse in the second sub-period.[24] For other GHGs, the most relevant sector for the emissions decrease is sector “agriculture” (1), due to the technological improvement. “Manufacture of chemicals” (13) has the worst performance as regards N_2O, although in the years 2000-2005 it gets better thanks to eco-technological improvements. For CH_4, “sewage and refuse disposal” (37) is also relevant. While in the first period there is an increase of emissions mainly caused by a strong positive final use volume change, in the second period the sector reveals a strong technological improvement (-7.5%) that causes the emissions to fall down.

Figure 2.2. SDA for GHG emissions index by sector, 1995-2000



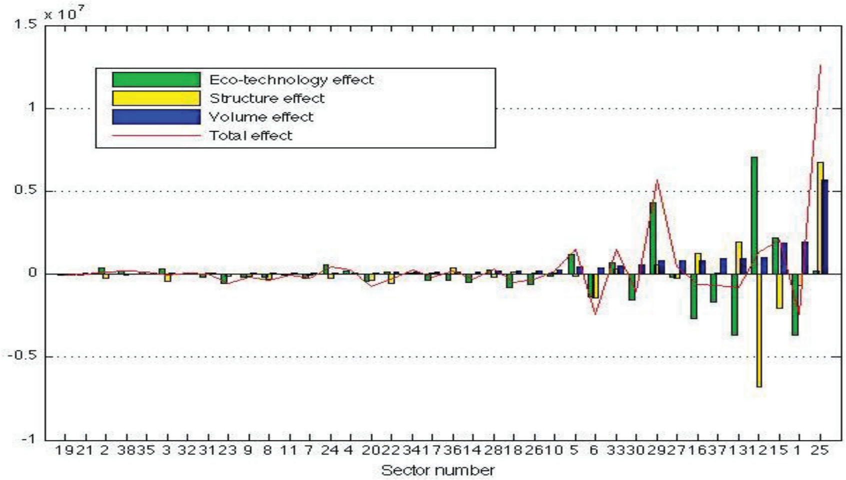
Unit: tons.

Source: own elaboration from ISTAT data (ISTAT 2010a, 2010b).

[23] The number in parenthesis after a sector’s name refers to sectors numbers in Figures 2.2 to 2.5 and Appendix 2.A.

[24] Another interesting result is that for sector “manufacture of coke” (12) the final use structure effect is significantly relevant: on the one hand it offsets the eco-technological improvement in the first sub-period, but on the other hand it keeps the emission increase low in the second sub-period, when a bad eco-technological performance would have brought a strong emission increase.

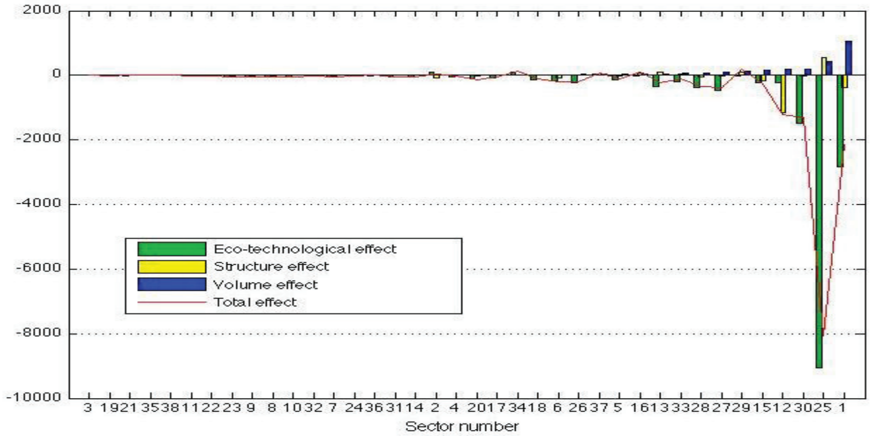
Figure 2.3. SDA for GHG emissions index by sector, 2000-2005



Unit: tons.
Source: own elaboration from ISTAT data (ISTAT 2010a, 2010b).

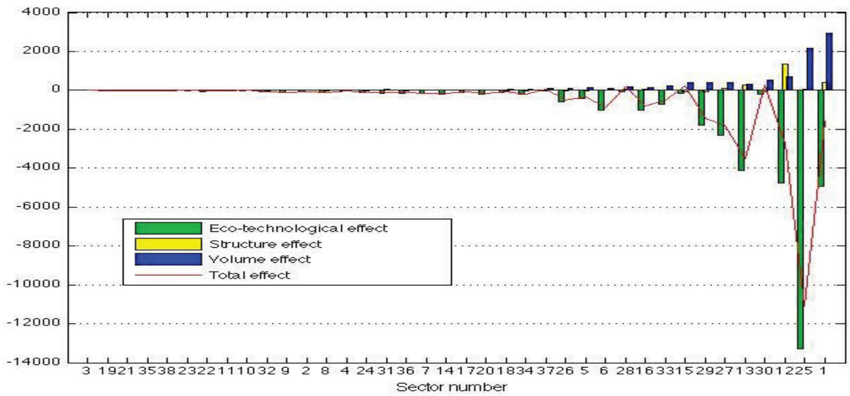
As regards acidifying index, important changes in emissions are concentrated on few relevant sectors (Figures 2.4 and 2.5). For both NO_X and SO_X the main responsible for emissions decrease is "electricity" sector (25), thanks to an important improvement in eco-technology. This result could seem in contrast with the previous result, where "electricity sector" (25) was found to be the most polluting one in terms of CO_2. Possible explanations can be, on the one hand the fuel switch from oil to gas that characterized the Italian electricity industry in the considered period; on the other hand during the same period important NO_X and SO_X abatement regulations took place, such as the EU legislation (European Parliament and Council, 2011) to reduce these pollutants in large combustion plants. For NO_X emissions, during the period 1995-2000 the decrease of emissions is driven, through a strong technological improvement, by sectors "manufacture of chemicals" (13), "electricity'" (25), "wholesale and retail trade" (27), and "land transport" (29), and during the second period by sectors "electricity" (25), and "water-air transport" (30), although the first one reduces to one third its contribution (from -11% to -3.6%). For SO_X, sectors "manufacture of coke" (12), "manufacture of chemicals" (13), and "electricity sector" (25) are the most relevant for the reduction of emissions, due also in this case to a technological improvement. In particular, in the second period, the eco-technological effect change for "electricity sector" (25) is closed to -35%. The general decrease of ammonia (NH_3) is quite totally due to sector "agriculture" (1), for both periods.

Figure 2.4. SDA for acidification emissions index by sector, 1995-2000



Unit: tons.
Source: own elaboration from ISTAT data (ISTAT 2010a, 2010b).

Figure 2.5. SDA for acidification emissions index by sector, 2000-2005



Unit: tons.
Source: own elaboration from ISTAT data (ISTAT 2010a, 2010b).

Moving to the analysis of the emissions without trade, as for the economy as a whole, also the SDA at the sector-based level reveals trends that are quite similar, though for some sectors the analyses show different results. Appendix 2.B presents a graphic comparison between the two SDA results for each gas.

In some cases, the sector-based analysis shows that few main sectors are responsible for the difference between territorial emissions and the emissions Italy would have produced without trade. In most cases sectors would have emitted more without trade. Regarding N_2O, "manufacture of chemicals" (13) is the main responsible of a worse performance of emissions in absence of trade: introducing imports nullifies the eco-technological improvement of the domestic technology. Similarly, sector "mining of energy producing materials" (3) is the main responsible for the higher emissions without trade in the case of CH_4. For NH_3, the main responsible is sector "agriculture" (1). In both cases technology is worse when we include imports. Conversely, sector "manufacture of coke" (12) would show a stronger SO_X emissions decrease without trade, thanks to a better technology and a better structure of final use.

In other cases – as the case of the worse performance for CO_2 and NO_X – is not possible to trace back differences only to few sectors because differences are spread among many sectors of the economy.

Finally the analysis at a sector-based level is able to highlight some differences hidden in the analysis at a global level. Without trade "manufacture of chemicals" (13) would perform better in the first period regarding SO_X emissions. Always without trade "water-air transport" (30) would emit more NO_X due to a worse structure of final demand and a worse technology.

Table 2.7 summarizes the main results for the most relevant sectors in the evolution of emissions for both analysis considered. In general, the two SDA proposed at a sector level highlight some differences in responsibilities, but at a global level, in the case of Italy, the migration of highly pollution-intensive industries abroad do not seem strongly supported by this analysis.

Table 2.7. Relevant sector for the evolution of emissions, 1995-2005

1: Agriculture, hunting and forestry
NO_X In the first period it reveals a technological improvement compensated by the increase of final use volume. **NH_3** It is the most important sector in the negative total emissions variation, that is higher in the second period for the important reduction of the final use volume effect. **N_2O** Also for this gas it is the most important sector. In both periods there is a strong technological improvement. The reduction of total emissions level in the second period is also due to the end of positive final use structure and the decrease of the positive volume variation. **CH_4** It is the most important sector in reducing emissions. The path is the same as for NH_3 and N_2O.
3: Mining and quarrying of energy producing materials
CH_4 Results change depending on the different SDA. In both periods the increase of emissions is higher if we consider emissions without trade. In the first period this is due to a worse performance of all the factors considered, while in the second period there is due to a worse eco-technological effect and a worse final demand structure.
12: Manufacture of coke, refined petroleum products and nuclear fuel
SO_X In both periods there is a strong negative total emissions variation that corresponds in the first period to technological improvement (-10.5%), while in the years 2000-2005 it is explained by a strong negative final use structure effect variation. **CO_2** While in the first period the sector contributes to the reduction of emissions through an eco-technological improvement, in the second period though the final use structure variation becomes negative, the eco-technological effect variation as well as the total effect variation have positive sign. It is the only sector that shows a better path if we consider emissions without trade for both SO_X and CO_2.
13: Manufacture of chemicals, chemical products and man-made fibres
SO_X It is a relevant sector for the decrease of emissions brought about by technological improvement for both periods, although the result is quite less effective in the years 2000-2005. **CO_2** Its contribution to the decrease of emissions is relevant just in the first period. **N_2O** In the first period, even with technological improvement, positive final use structure and volume cause emissions to growth, while in the second period the different factors offset each other. Considering emissions without trade, the responsibility for the growth of emissions in the first period is caused by a worse technological effect and not by the final use structure effect.
25: Electricity, gas and water supply
NO_X In both period it is one of the most relevant sectors for the decrease of emissions, though in the years 2000-2005 its contribution falls from -11% to -3.6%. **SO_X** It contributes to the decrease of emissions through technological improvements in both periods, counting in the second one for a reduction of emissions close to 30%. **CO_2** Though in the years 1995-2000 there is a negative technological effect variation, it is offsets by a positive final use structure effect variation that causes emissions to increase. In the second period the technological improvement ceases to exist.
27: Wholesale and retail trade; repair of motor vehicles, motorcycles and personal and household goods
NO_X It contributes to the decrease of emissions in a relevant way only in the first period. **CO_2** As for NO_X emissions, its contribution to the reduction of emissions due to a technological improvement is relevant only in the first period.
29: Land transport; transport via pipeline
NO_X In the first period it is a relevant sector for the decrease of emissions due to a technological improvement.
30: Water transport, Air transport, Supporting and auxiliary transport activities; activities of travel agencies
NO_X While in the first period it causes an increase of emissions and it is the sector that shows the worst relation between absolute level of emissions in 1995 and emissions variation, in the second period it is the only sector with sector 25 that becomes relevant for the decrease of emissions due to a technological improvement. Its evolution in the first period is worse if we consider emissions without trade due to a positive final use structure variation.
37: Sewage and refuse disposal, sanitation and similar activities; Activities of membership organizations; Other service activities (O90, O91, O93)
CH_4 While in the first period there is a positive final use effect variation that causes emissions to increase, in the years 2000-2005 a strong technological improvement contributes to a relevant decrease of emissions.

Source: own elaboration.

2.5. Conclusion

In this work, the interest was to highlight how different economic factors have driven the evolution of Italian emissions during the years 1995-2005 through SDA. We examined three GHG gases (CO_2, N_2O, CH_4) and three acidification gases (NO_X, SO_X, NH_3). The driving forces considered relevant are eco-technological effect, final demand structure and final demand volume. The exercise deals with international trade by analyzing both the emissions caused by the local production processes, or territorial emissions, and the emissions that the country would have produced without international trade.

Considering emissions related to the actual productive processes we compare the role of domestic input structure against the role of the demand that the productive system satisfies. Considering emissions without trade we compare the role of technology by including also imported inputs against the role of the total domestic demand. If on the one hand the two analyses permit to take into account trade, on the one hand the main limitation of this proposal is that the interpretation of the comparison is not immediate because all the factors are changing. However, the analysis gives information on the different forces underlying the evolution of emissions for the different sectors considered, and it is a useful instrument in order to highlight the critical sectors for the achievement of the emissions reduction targets.

In general, for both periods, a negative eco-technological effect reduces the growth of emissions that otherwise the increase of the final use volume effect would cause. In the second period technological effect is less effective, while the decrease of the positive final use effect variation and a negative final use structure variation become more relevant for the decrease or the retention of emissions. If on the one hand this result reveals the importance of eco-technological effect in reducing the emissions, on the other hand it also underlines the role of final demand in causing emissions to increase, and this should be taken into account in order to figure out adequate policies for reaching the emissions reduction targets.

The main difference between CO_2 emissions and all the other gases is the absence of an important technological improvement, in particular for the second period, when for CO_2 the technological component becomes responsible of the increase of emissions.

These general trends can considerably change depending to the sector considered. Moreover, the analysis at a sector-based level reveals the crucial role of some sector for the reduction of acidification emissions (agriculture, refusal disposal, land and water transport, electricity sector, manufacture of coke and chemicals). Another interesting result is the different responsibility of the electricity sector for the evolution of the different gases considered.

In terms of the economy as a whole, the comparison between the two SDA does not reveal major changes. The way in which technology, volume of final demand, and its structure influence the evolution of emissions is similar when considering territorial emissions or when considering emissions that Italy would produce without international trade. Hence, a first conclusion is that there was not a strong movement of the Italian production abroad to reduce the environmental impact. This result is different from the main findings of Campanale and Femia (2012) who analyze possible leakage in Italy through a SDA.[25]

Instead, the sector-based analysis shows that for some sectors the emissions evolution is influenced to some extent by the evolution of international trade. Specifically these sectors are agriculture, mining of energy producing materials, manufacture of coke, manufacture of chemicals, and water-air transport. An interesting extension of the analysis proposed could therefore be a more detailed study of these economic sectors.

We can finally conclude that the intent to analyze the evolution of emissions from different perspective reveals some differences and it seems to be useful for quantifying the responsibility of different sectors and different economic factors. Anyway, results seem to show equilibrium in the balance of emissions for Italy between 1995 and 2005. Since an update version of the emissions data has been lately released, it would be useful to extend this analysis enlarging its time scope in order to verify if the same trends still exist.

[25] Campanale and Femia (2012) estimate the emissions avoided through trade through a method different from the one applied in this study. Results might be indeed not strictly comparable.

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Appendices

Appendix 2.A. Economic sectors

Table 2.A.1. Economic sectors analyzed

N°	NACE rev 1.1	Economic Activities
1	A1-A2	Agriculture, hunting and forestry
2	B5	Fishing
3	C10-C12	Mining and quarrying of energy producing materials
4	C13- C14	Mining and quarrying, except of energy producing materials
5	D15-D16	Manufacture of food products, beverages and tobacco
6	D17	Manufacture of textiles
7	D18	Manufacture of wearing apparel; dressing and dyeing of fur
8	D19	Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear
9	D20	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
10	D21	Manufacture of pulp, paper and paper products
11	D22	Publishing, printing and reproduction of recorded media
12	D23	Manufacture of coke, refined petroleum products and nuclear fuel
13	D24	Manufacture of chemicals, chemical products and man-made fibres
14	D25	Manufacture of rubber and plastic products
15	D26	Manufacture of other non-metallic mineral products
16	D27	Manufacture of basic metals
17	D28	Manufacture of fabricated metal products, except machinery and equipment
18	D29	Manufacture of machinery and equipment n.e.c.
19	D30	Manufacture of office machinery and computers
20	D31-D32	Manufacture of electrical machinery and apparatus n.e.c., Manufacture of radio, television and communication equipment and apparatus
21	D33	Manufacture of medical, precision and optical instruments, watches and clocks
22	D34	Manufacture of motor vehicles, trailers and semi-trailers
23	D35	Manufacture of other transport equipment
24	D36-D37	Manufacture of furniture; manufacturing n.e.c., recycling
25	E40-E41	Electricity, gas and water supply
26	F45	Construction
27	G50-G52	Wholesale and retail trade; repair of motor vehicles, motorcycles and personal and household goods
28	H55	Hotels and restaurants
29	I60	Land transport; transport via pipelines
30	I61-I63	Water transport, Air transport, Supporting and auxiliary transport activities; activities of travel agencies
31	I64	Post and telecommunications
32	J65-J67	Financial intermediation
33	K70-K74	Real estate, renting and business activities
34	L75	Public administration and defence; compulsory social security
35	M80	Education
36	N85	Health and social work
37	O90,O91,O93	Sewage and refuse disposal, sanitation and similar activities, Activities of membership organizations n.e.c., Other service activities
38	O92	Recreational, cultural and sporting activities

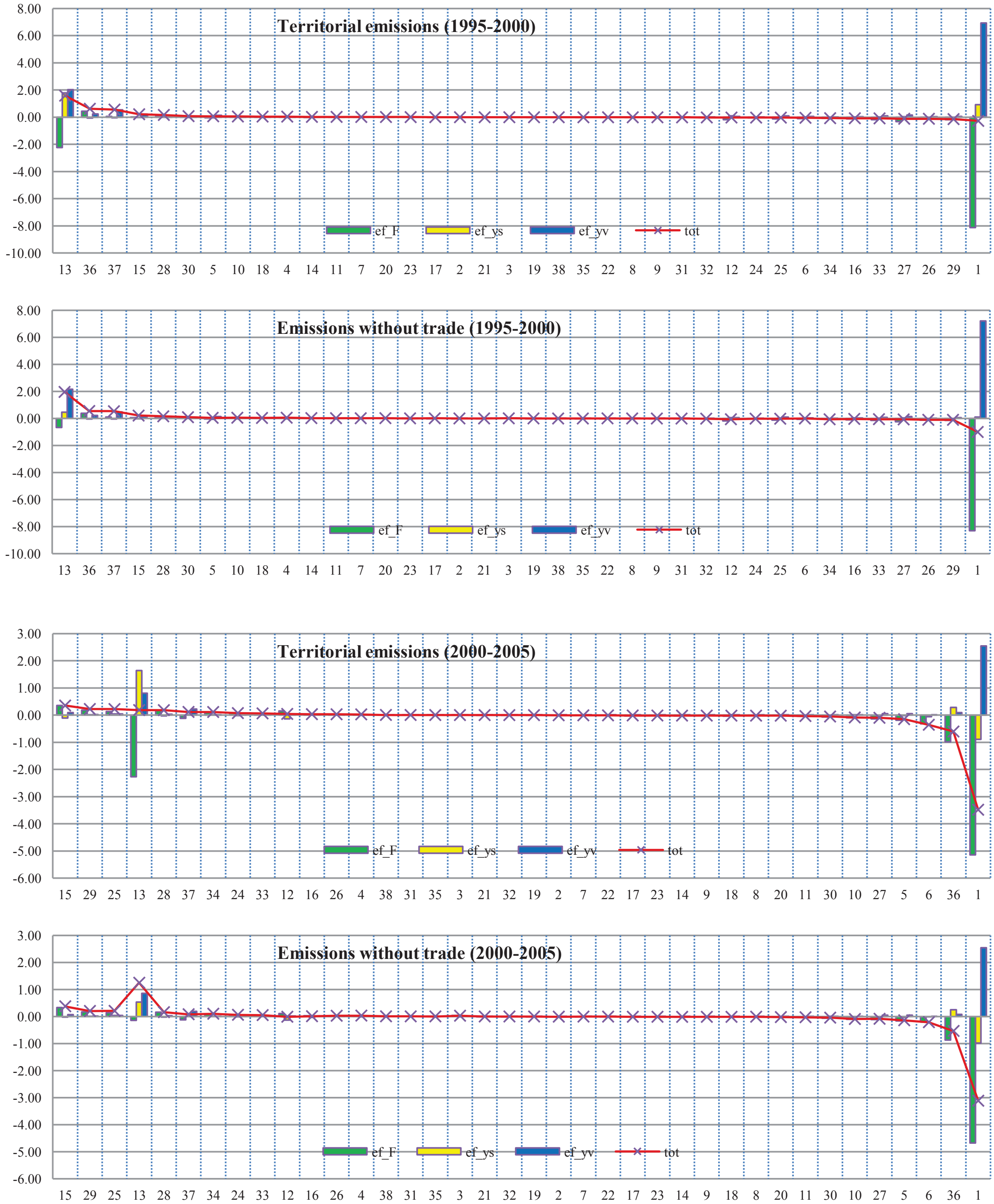
Source: own elaboration.

Appendix 2.B. Graphic comparisons between the two SDAs

Figure 2.B.1. SDAs for CO_2 emissions for the two sub-periods

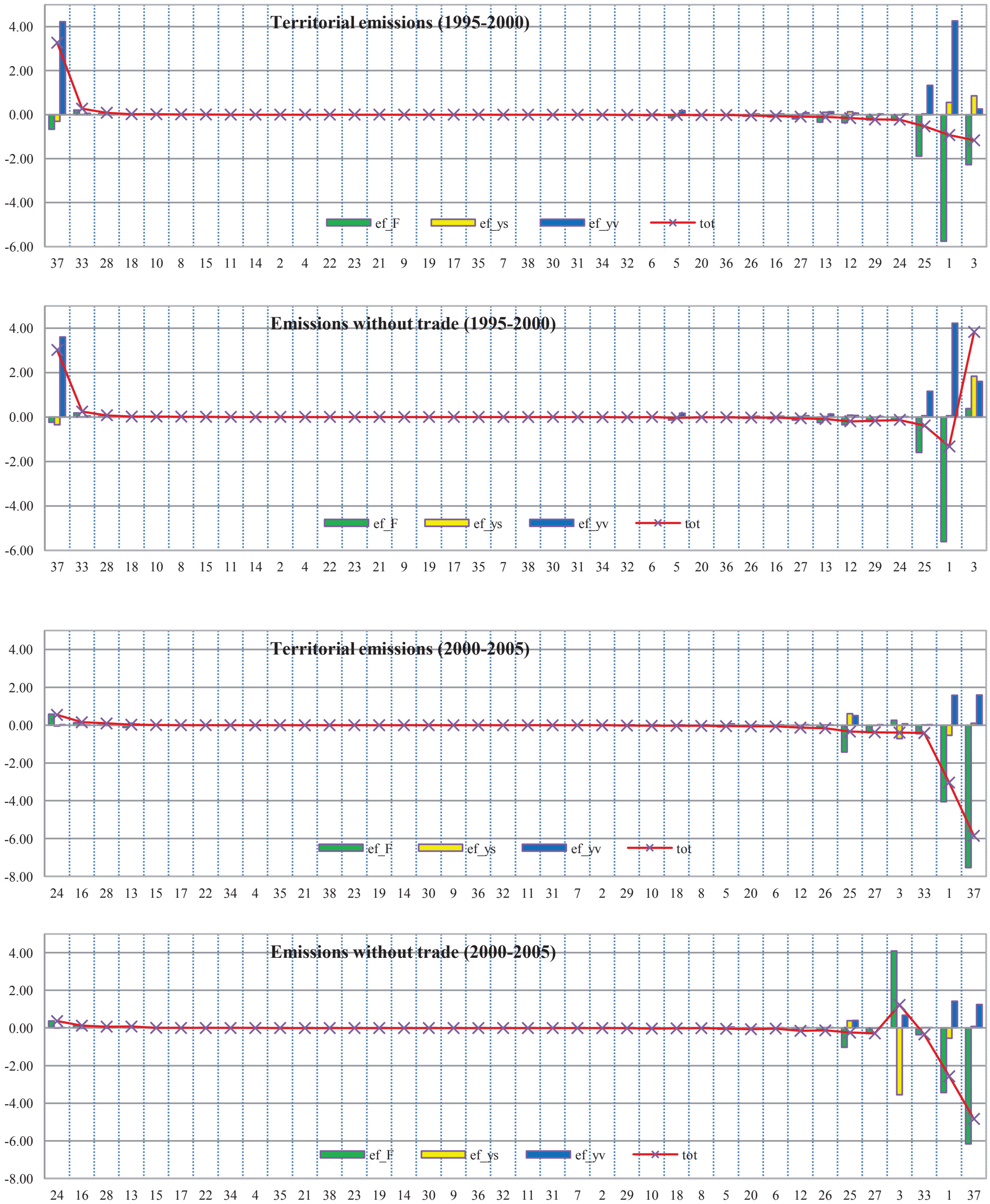
Source: own elaboration from ISTAT data (ISTAT 2010a, 2010b).

Figure 2.B.2. SDAs for N_2O emissions for the two sub-periods



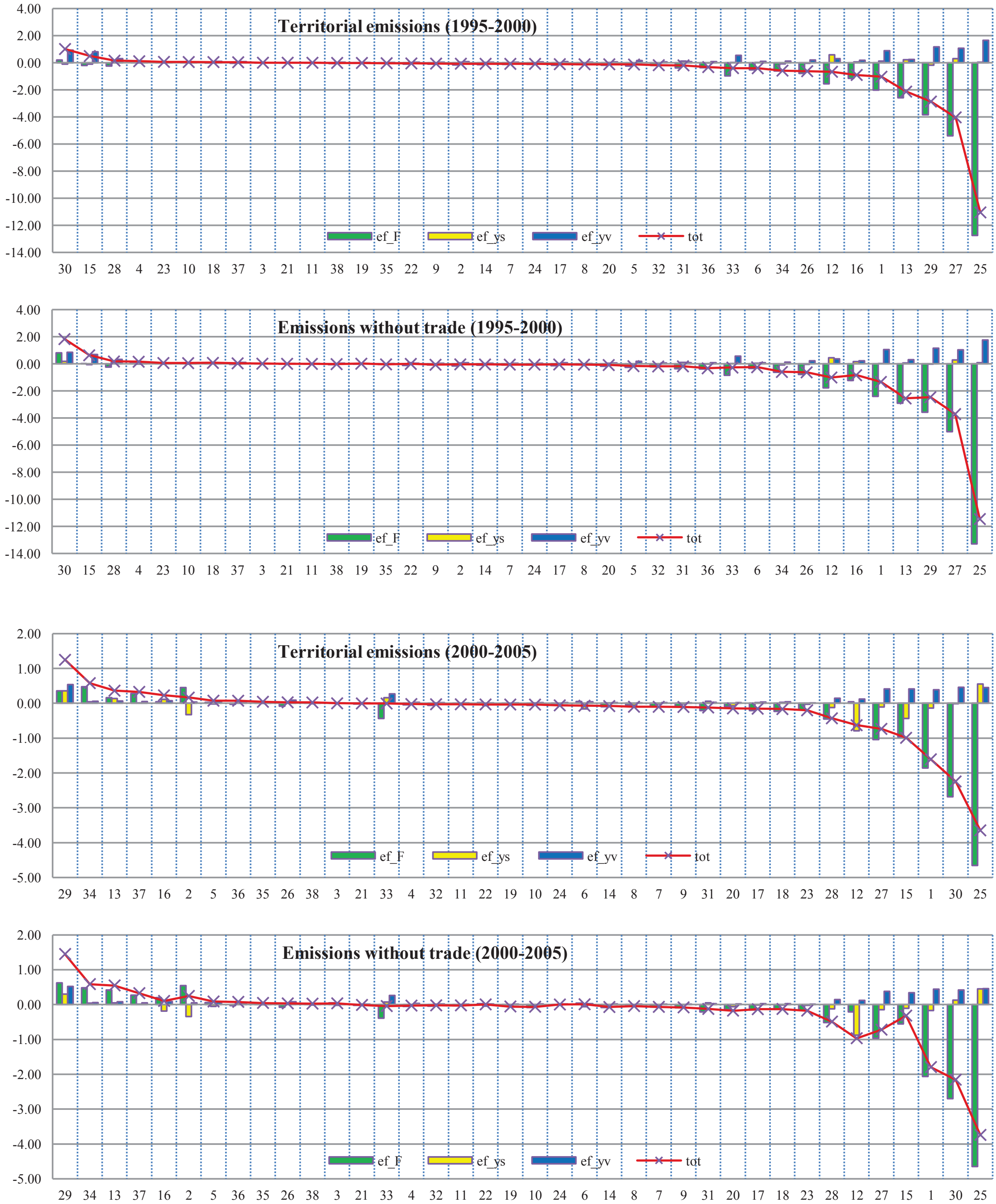
Source: own elaboration from ISTAT data (ISTAT 2010a, 2010b).

Figure 2.B.3. SDAs for CH_4 emissions for the two sub-periods



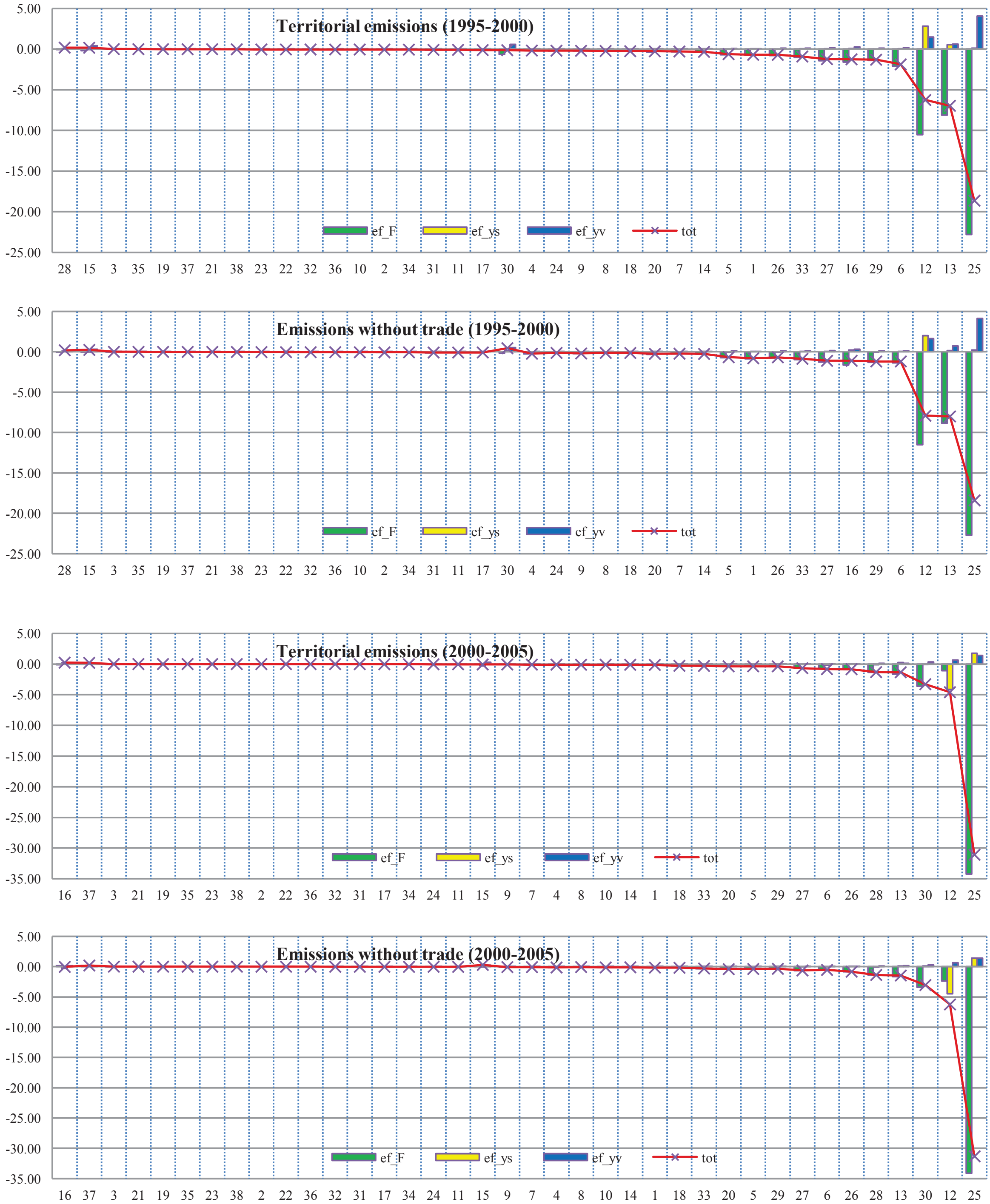
Source: own elaboration from ISTAT data (ISTAT 2010a, 2010b).

Figure 2.B.4. SDAs for NO_X emissions for the two sub-periods



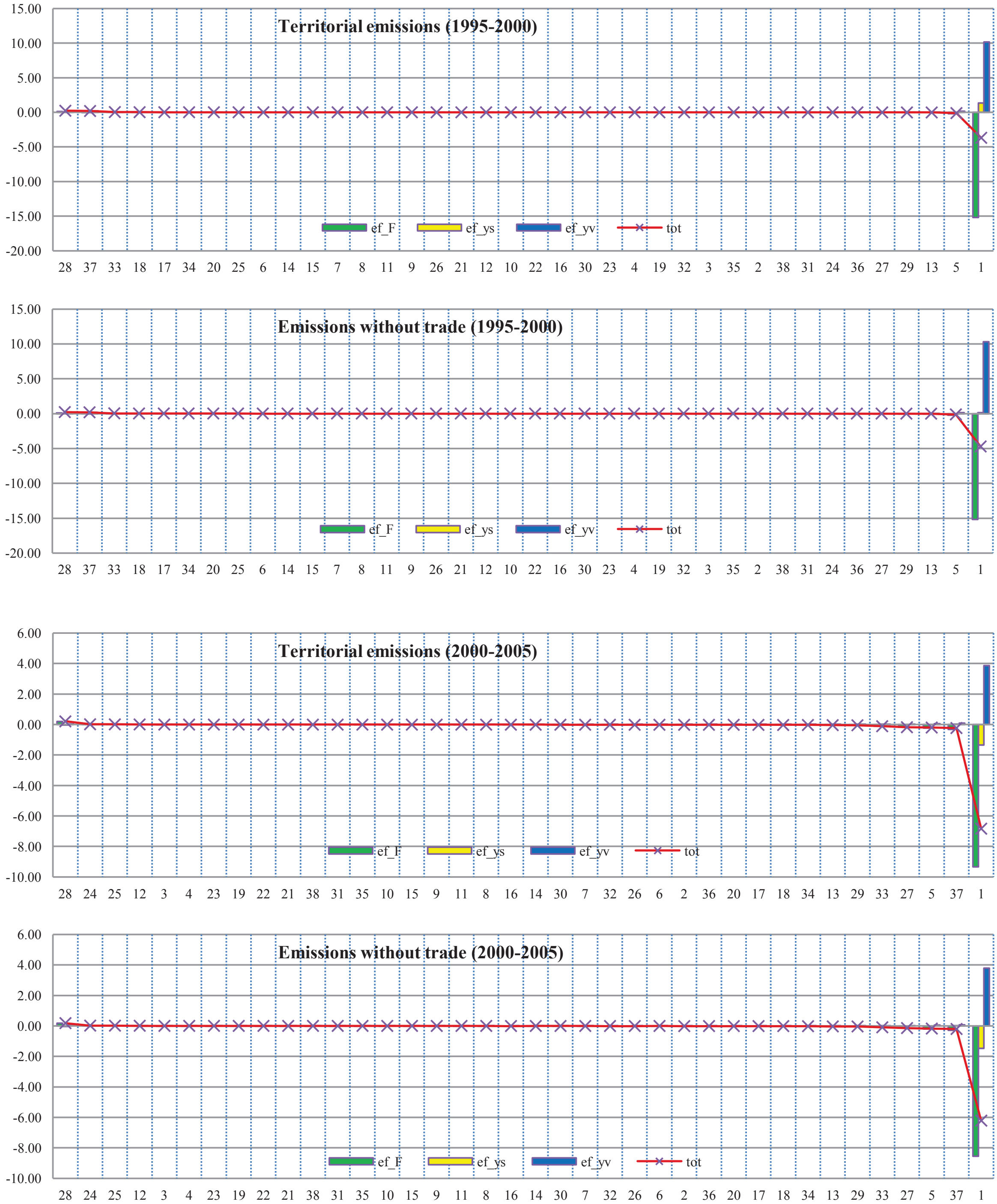
Source: own elaboration from ISTAT data (ISTAT 2010a, 2010b).

Figure 2.B.5. SDAs for SO_X emissions for the two sub-periods



Source: own elaboration from ISTAT data (ISTAT 2010a, 2010b).

Figure 2.B.6. SDAs for NH_3 emissions for the two sub-periods



Source: own elaboration from ISTAT data (ISTAT 2010a, 2010b).

Chapter 3

The reform of the European Energy Tax Directive: exploring potential economic impacts in the EU27

3.1. Introduction[26]

Policy instruments aimed at reducing emissions are widely recognized as a necessary intervention to mitigate the impact risks related to atmospheric contamination and climate change. Through policy interventions, legislators try to reduce polluting behaviors and to encourage a more respectful conduct and more efficient technologies. There are several tools for emissions control, many of which use economic mechanisms to influence the existing patterns of production and consumption. These instruments, generally classified in price-mechanisms and quantity-mechanisms, should minimize abatement costs by creating an incentive to develop alternative technologies or to use alternative energy products.

In Europe, although each country has the legal competency to regulate emissions, the European Union (EU) takes part in this process too. One of

[26] This Chapter was originally published in Energy Policy (2014), vol. 75, 341-353. It was presented to the XVI Encuentro de Economía Aplicada (Granada, 2013), the V Spanish Conference of Input-Output Analysis (Sevilla, 2013), and the XXI International Input-Output Conference (Kitakyushu, 2013). I thank the participants for useful comments. I also thank Malina Koleshanska and Vassil Shivkov from the European Directorate for Taxation and Customs Union for their clarifications on the European documents analyzed.

the instruments implemented at European level is the minimum energy tax on the use of energy products, currently ruled through the Energy Tax Directive (ETD).

In 2011, the European Commission (EC) proposed a new version of the current ETD in order to strengthen its effectiveness, but the European Parliament blocked the process in 2012 and the reform was not accepted. The political process that leads to the implementation or, as in this case, the renewal of a policy instrument is often slow and difficult due to the complexities involved. The 2011 ETD reform was a political reform inherently difficult to be achieved that aroused the reaction of various interest groups. Such reform, which sought to rebalance the current treatment of different energy products used by different sectors, would have affected many economic agents and many countries that have different priorities regarding the climate change policy.

However, it is equally clear that, given the environmental objectives that the EU has set itself, and given the difficulties that the carbon market is facing, the 2011 ETD reform could have been a very moderate but useful step forwards the policy on climate change. This is the main reason that led us to ask what economic impact it would have if approved. As far as we know, there are almost no studies on the potential economic implications of the 2011 ETD reform, although such analyses could bring some evidence to the debate. Barker et al. (1993) and Manne and Richels (1993) analyzed the previous proposal of the Commission to renew the ETD in 1992, but there are no similar studies regarding the recent one. This analysis tries to fill this lack.

Following the idea of Nguyen (2008) who examines the impact on prices of the Vietnamese program to increase taxes on electricity, we analyze the potential effect on prices that the implementation of the EU tax energy reform would cause on different sectors and EU countries. We use a multi-region and multi-sector database that allows us to consider international trade flows within the EU and with the rest of the world. The results of our simulation are an interesting starting point to answer a simple question: would the reform imply a strong economic impact on costs and prices?

To contextualize the analysis, the following subsections describe the main economic instruments for emissions control implemented in the EU so far (3.1.1) and the energy tax reform proposed by the EC in 2011 (3.1.2).

Section 3.2 presents the methodology and Section 3.3 the database. Results are presented in section 3.4. Section 3.5 concludes and gives some policy implications of this research.

3.1.1. Energy tax and emissions trading: current status

Looking at different policies that can be used to reduce carbon dioxide (CO_2) emissions, two main market instruments exist: carbon (or energy) taxes and carbon emissions trading.[27] Energy taxes try to affect the emissions quantity by increasing the price of energy products. The emissions trading is a "cap and trade" system that fixes a total amount of CO_2 emissions allowances that are distributed among economic agents who can either use or trade them, letting the market determine their price and final distribution. In particular, the EU has implemented both instruments, approving the ETD and introducing an Emissions Trading System (ETS).

Energy taxes are not a recent phenomenon in Europe; European countries have been using them for nearly ninety years, although initially the aim was only to raise revenues and to reduce oil imports.[28] It was during the 1980s when some European countries started thinking on the energy taxes as an instrument for emissions control. In 1992, the EC presented the first proposal (European Commission, 1992) that reflected strong environmental concerns, recommending a tax on the use of energy products that explicitly referred to the CO_2 emissions content. However, this ambitious plan found the opposition of some countries and the text that was actually approved by the Council in the same year was much more modest (European Council, 1992); it was mainly focused on regulating the minimum harmonized taxation on mineral oils and natural gas by imposing relevant rates only for motor fuels. Since then, the EC has started a slow and difficult process aimed at enlarging the scope of this instrument to more energy products, strengthening its climate change policy, and harmonizing the legislation among the member states of the EU. The unanimity rule for fiscal decisions in the EU was the main obstacle to approve the subsequent attempts of the EC in 1995 and 1997 (European Commission, 1995, 1997).

[27] Compared with non-market instruments, market instruments imply efficiency gains because the marginal cost of emitting an unit of CO_2 is the same for all emitters resulting in a cost-efficient reduction of total emissions (Tietenberg and Lewis, 1984).

[28] See Hasselknippe and Christiansen (2003), Speck (2008), Weisbach (2011) for a history of energy taxes in Europe.

Anyway, this process led to the adoption of the current regulation approved in 2003. The current 2003 ETD constitutes an important improvement compared to the 1992 legislation: it widens the scope of the energy taxation to other energy products, and it increases the minimum rates that countries must take into account when enacting their national implementation.[29] Nonetheless, despite the important achievements reached with the 2003 ETD, its environmental targets are still limited. Indeed, considering the dependence and intensity in the use of energy products for some industries and the impact of taxation in terms of competitiveness, the 2003 ETD proposes a complex system of reductions and exemptions that has been denounced as a factor that might reduce the environmental effectiveness of this type of taxes (Ekins and Speck, 1999). Moreover, in the current directive there are other elements that could suggest the need for a legislative renewal: in particular, the absence of a signal that clearly reflects CO_2 emissions and the energy content of the products, the absence of incentives to develop markets for alternative energies, and the absence of coordination with the European ETS approved afterwards (European Commission, 2011).

All these difficulties of setting a carbon tax raised the need for alternative emissions control tools. The process to create a European emissions trading mechanism did not start before the late 1990s influenced by the international context. In 1997, despite the initial opposition of Europe, within the Kyoto Protocol negotiations “flexible mechanisms” for emissions control such as the emissions trading between countries were introduced. In this context, in 1998 the EC proposed to create an internal ETS focused on individual companies (European Commission, 1998); the emissions market, defined as one of the EU’s flagship of the climate change project (Vlachou, 2014), was finally approved in 2003 (European Parliament and Council, 2003) and was launched in 2005.[30] Since the allowances were basically distributed for free considering historical emissions grandfathering, the most part of them were given to large

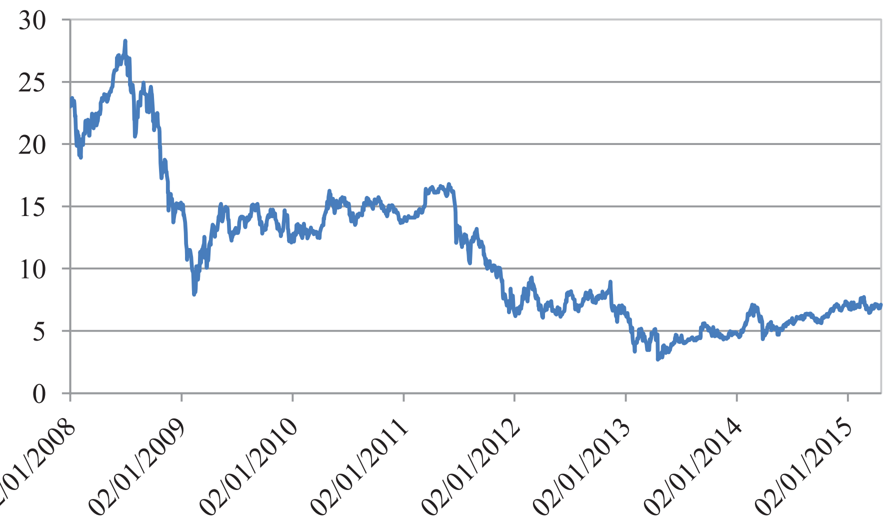
[29] Moreover, the 2003 ETD distinguishes between motor fuels and other uses of energy products and between business and non-business activities.

[30] Meanwhile, in 2004 it was approved that enterprises of the EU could obtain carbon credits from investments in other countries in order to accomplish the limits established by the ETS allowances. The two mechanisms, implemented by the Kyoto Protocol, were the so-called “clean development mechanism” (CDM) and the “joint implementation” (JI) (European Parliament and Council, 2004).

installations belonging to energy-intensive sectors. Practically, the main activities that enter the ETS mechanism are energy activities (such as combustion installations, mineral oil refineries and coke ovens), production and processing of ferrous metals (such us metal ore and production of pig iron), activities from mineral industry (such as installation for the production of cement, glass and ceramic product), and other industries as industrial plants for the production of pulp from timber and paper. Aviation was included in the ETS in 2012 but, due to international conflicts, initially it was only applied to internal flights in Europe.

A first learning phase of the European ETS (2005-2007) was followed by a second stage (2008-2012) that corresponded to the Kyoto Protocol commitment period, and now the market is in its third phase (2013-2020). Although a major revision approved in 2009 tried to strengthen the system (European Parliament and Council, 2009), the mechanism is now under many criticisms (see Branger et al., 2013). One of the weakest points of this is the volatility of allowance price over time, which has been much lower than expected during the last years (see Figure 3.1). Without a credible and significant price signal both in the short and in the long term, it is not possible to create an incentive for firms to invest in low carbon technologies.

Figure 3.1. EU ETS: Average of daily closing price



Unit: euro per ton of CO_2.
Source: own elaboration from Sendeco data (Sendeco, 2015).

3.1.2. The 2011 ETD reform proposal

In 2011 the EC proposed a new version of the European ETD (European Commission, 2011). The main aim of the new proposal was to increase the effectiveness of this tool through the implementation of three main changes. First, the proposal fixed higher minimum rates in an attempt to strengthen the incentive for energy efficiency and to cause a shift toward less polluting production and consumption patterns. Second, as in the 1992 proposal, existing energy taxes were split into two components that, taken together, would determine the overall rate at which a product is taxed. One component was based on the energy content, which was different depending on the use of energy products. The other component was specifically linked to CO_2 emissions.[31] The aim of this novelty was twofold. On the one hand, an explicit carbon tax component would be introduced in order to underline the climate change policy. On the other hand, it tried to establish a comprehensive and consistent signal of the CO_2 allowance price in order to complement the European ETS; indeed, the plants affected by the ETS would have only been affected by the energy component and not by the CO_2 component to avoid a double burden. Finally, the new text also tried to restructure and simplify reductions and exemptions, limiting them to the energy taxation based on the energy content and removing unjustified subsidies for certain fossil fuels, such as diesel and coal. Tables 3.1 and 3.2 resume the main changes proposed.

Nonetheless, in May 2012 the process of updating stopped; the EC's proposal was not supported by the European Parliament and the 2003 directive continues in force. The main worry seemed to be the effect of such proposal on competitiveness caused by the induced increase in prices. In particular, the concern was about sectors that would be mainly affected given the intensive use of energy products (Euractiv, 2012). Conversely, the advocates of the reform argued that the impact of the environmental tax reform, for example on diesel prices, has been overestimated since today tax rates are higher than the new minima proposed in the majority of the EU countries.[32]

[31] In practical terms, for energy products that are not used as motor fuels the energy component was very low in comparison with the CO_2 component.

[32] Astrud Lulling, the Parliament's report lecturer, referred to direct negative social impact from higher prices for coal, natural gas, heating oil and diesel oil. Three major European automobile manufacturer associations (ANFIA for Italy, CCFA for France and

Table 3.1. The 2003 ETD and the 2011 ETD reform proposal

ETD (2003)	
Energy products	Petrol, gas oil, kerosene, liquefied petroleum gas, natural gas, heavy fuel oil, coal and coke, electricity.
Scope	The directive fixes minima for mineral oils as well as for coal, gas, and electricity. These products are taxed only if burnt, and are levied with different rates depending on their uses (motor fuels, heating, industrial use). They are not under the directive scope when they are used as raw materials, in chemical reductions or in electrolytic or metallurgical processes.
ETD (2003) and ETD reform proposal (2011): main changes	
2003	**2011**
The taxable base for mineral oils is the volume while for coal, gas and electricity is the energy content	The tax rate is calculated according to CO_2 emissions content (20€/ton) and energy content (9.6€/GJ if products are used as fuels, 0.15€/GJ if products are used for heating).
Minimum rate are fixed (see Table 2).	Higher minimum rate are proposed (see Table 2).
Member states are allowed to provide for a lower rate on commercial diesel.	It is not allowed any exemption or reduction below the minima related to the CO_2 emissions content.
Member states can reduce tax rates if businesses are energy intensive.	
Member states can exempt the agricultural sector.	

Source: own elaboration.

Table 3.2. Minima rates in the 2003 ETD and minima rates in the 2011 ETD reform

	Current minima	Minima proposed in ETD reform		
		Energy content	**CO_2 emissions**	**Total**
Motor fuels		**(9.6 €/GJ)**	**(20 €/ton)**	
Petrol (€ per 1000 l)	359	314	46	360
Gas oil (€ per 1000 l)	330	337.9	52.1	390
Kerosene (€ per 1000 l)	330	340.6	50.9	392
LPG (€ per 1000 kg)	125	442	58	500
Natural gas (€ per GJ)	2.6	9.6	1.1	10.7
Heating fuels and motor fuels for industrial use		**(0.15 €/GJ)**	**(20 €/ton)**	**Total**
Gas oil (€ per 1000 l)	21	5.28	52.1	57.37
Heavy fuel oil (€ per 1000 kg)	15	6	61.84	67.84
Kerosene (€ per 1000 l)	0	5.32	51	56.3
LPG (€ per 1000 kg)	0	6.9	58	64.86
Natural gas (€ per GJ)	0.15	0.15	1.12	1.27
Coal and coke (€ per GJ)	0.15	0.15	1.89	2.04
Electricity				
Electricity (€ per MWh)	0.5	0.54	--	0.54

Source: European Commission (2011).

VDA for Germany) have issued a joint statement calling on the European Parliament and the Council to disassociate them from the proposed increase in taxation diesel. On the other hand, Algirdas Semeta, commissioner for taxation and customs, said that the impact on diesel prices has been overestimated. He stressed that diesel use is a major concern for the EC because of the European dependence from import, which causes prices variations stronger that the prices variation the reform would imply. See National Association of the Automotive Industry et al. (2011), Euractiv (2012), Greenreport (2012), Reuters (2013).

3.2. Methodology

Today's products and services are no longer produced within a single country; instead, they are made in global supply chains. A multi-country and multi-sector model is needed to take into account all these country-to-country interdependencies in the production processes.

We consider a world economy consisting of *c* countries. Each country is composed of *n* sectors, which produce one single product (x_i^r) that might be used (either at home or abroad) by other sectors as intermediate input (x_{ij}^{rs}) or consumed or invested as final product by final user categories such as households and the government (f_i^{rs}), although household consumption is the most important part of the final use. These monetary transactions are represented by $x_i^r = \sum_{j=1}^{n} \sum_{s=1}^{c} x_{ij}^{rs} + \sum_{s=1}^{c} f_i^{rs}$, where x_{ij}^{rs} indicates the monetary value of goods and services from industry *i* in country *r* that are used as intermediate input in industry j in country s, and f_i^{rs} indicates the deliveries in monetary units from industry i in country r to final users (mainly households) in country *s*. The technology of this world economy is be represented by **A**, whose elements are $a_{ij}^{rs} = \frac{x_{ij}^{rs}}{x_j^s}$.[33]

Final users (mainly consumers) are at the end of the global supply chains and are the ultimate users of all production. Hence, if producers pass on their production costs to the buyers of their products, the final users (consumers) will bear the full burden. In that case, the accounting expression will be $x_j^s = \sum_{i=1}^{n} \sum_{r=1}^{c} x_{ij}^{rs} + v_j^s$, where now the monetary value of product *j* produced in country *s* is equal to total cost of its production, that is, the cost of intermediate inputs x_{ij}^{rs} plus the value added v_j^s.

An equivalent expression in matrix terms becomes $\mathbf{x}' = \mathbf{i}'\mathbf{X} + \mathbf{v}'$. Substituting $\mathbf{X} = \mathbf{A}\hat{\mathbf{x}}$ and post-multiplying by $\hat{\mathbf{x}}^{-1}$, the cost of inputs per unit of output is given by $\mathbf{p}' = \mathbf{p}'\mathbf{A} + \mathbf{w}'$, where $\mathbf{w}$ represents the value added per unit of output and $\mathbf{p}$ is the price vector in which each price is indexed and equal to 1. This expression leads to $\mathbf{p}' = \mathbf{w}'(\mathbf{I} - \mathbf{A})^{-1} = \mathbf{w}'\mathbf{L}$,

[33] Matrices are indicated by bold, upright capital letters; vectors by bold, upright lower case letters; and scalars by italicized lower case letters. Vectors are columns by definition, so that row vectors are obtained by transposition, indicated by a prime. A circumflex indicates a diagonal matrix with the elements of any vector on its diagonal and all other entries equal to zero. The notation **i** is used to represent a column vector of 1's of appropriate dimensions.

which indicates that changes in primary inputs prices lead to changes in sectoral unit cost and, therefore, to output prices. Whenever an additional cost per unit value of output $\mathbf{t}$ is added, the new price will be defined by $\widetilde{\mathbf{p}}' = (\mathbf{w}' + \mathbf{t}')\mathbf{L}$. This model implies that any additional cost is totally passed on final prices and there is not substitution of any kind. Thus, we are calculating, in fact, the maximum effect on prices of such additional cost.

The main advantage of this model is that it permits to simulate the effects of a policy change, such as the implementation of a new energy tax or the increasing of energy tax rates, taking into account not only the effect on each sector due to its use of energy products at home, but also the indirect effect caused by the increase of the price of all the other inputs produced in different countries but used at home. Taking into account that our analysis is on a taxation change affecting at the same time several countries with important trade relationships, the convenience of a multi-country model is even clearer.

For the analysis of the impact on countries, we summarize all the potential price changes into a synthetic measure that will allow us to compare the total effects of the energy tax reform among different countries. Considering only the household consumption, the main component of final demand, we compare the cost of the basket of goods that characterizes households' consumption before the implementation of the new energy tax with the cost of the same basket after the reform. However, the EU energy tax reform not only affects the use of energy products by sectors, but it also applies to energy products consumed directly by households. This price index is defined by W as:

$$W = \frac{\sum_{i=1}^{n} \tilde{p}_i q_i + \sum_{e=1}^{m} t_e q_e}{\sum_{i=1}^{n} p_i q_i} \tag{3.1}$$

Being q_i the quantity of goods and services i consumed by households, p_i the initial price of the commodity i, $\tilde{p}_i$ the new price after the proposal implementation, t_e the tax variation of each energy product e applied to households' consumption, and q_e the quantity of each energy product consumed by households.

It should also be stressed that the potential negative economic effects might be even lower than this index W suggests. First, because the model assumes that there is not technical change. Second, because the Laspeyres-type price index computed does not consider that consumers could react to the price variation changing the relative consumption of different goods and services (which is, in fact, the main environmental objective of carbon taxation). Finally, this analysis does not take into account that the new energy tax revenues could be used to decrease other taxes or to increase public expenses or to reduce public debt, generating in this way a positive effect not considered here.

A final remark about the computation of the new cost $\mathbf{t}$ is needed. Since our analysis considers the increased taxation as an additional production cost, it is necessary to work out what is the additional tax per unit of product that each sector would have faced if the reform proposal was implemented. Indeed, it is necessary to know, for every sector, the consumption of the different energy products per unit of output and the additional taxation on every energy product. So, vector $\mathbf{t}$ has been computed as $\mathbf{t} = \mathbf{D} \circ \mathbf{R}$, where $\mathbf{D}$ is the matrix of energy use coefficients, $\mathbf{R}$ is the matrix of tax rates variations, and $\circ$ is the element-wise product of matrices $\mathbf{D}$ and $\mathbf{R}$. In particular, $\mathbf{D}$ is obtained considering the energy flows from energy-producing sectors to all sectors (matrix $\mathbf{E}$) and the output produced by each sector $\mathbf{D} = \mathbf{E}\hat{\mathbf{x}}^{-\mathbf{1}}$.

3.3. Data description

Three main information sources have been used for this analysis: economic information about the inter-sector transactions inside each country and between countries, information about the energy use by sectors and by households, and information on current and new tax rates proposed by the European 2011 ETD reform.

Regarding the economic information, we use the multiregional input-output tables from the World Input-Output Database (WIOD) (Timmer, 2012; WIOD, 2012a). This database offers time series from 1995-2011 about inter-sector transactions of 35 sectors and 59 products; its geographic area refers to 41 countries: 27 EU counties, 13 other major countries in the world, and all the remaining countries aggregated in a single “rest of the world" region.[34] In particular, we use the world input-output table at current prices and international supply and use tables for the year 2008.[35]

For energy use, we use information from the environmental accounts of the WIOD for the year 2008 (WIOD, 2012b), in particular, the "Emission relevant energy use" tables. These data, which include energy flows in physical terms (terajoules, TJ) related to 26 energy products,[36] are derived from the gross energy use but excluding the non-energy use and the inputs for transformation into energy products.[37] The economic and energy information refers to 2008 due to data availability.

As regards energy taxation, it is necessary to know the current regime applied in the EU countries, and what changes the implementation of the EC proposal in 2011 would cause. Regarding the current environmental taxation regime, two sources of information are used: the "Taxes in Europe" database from the EC (European Commission, 2014), and the updating to 2013 of the tax regimes implemented in the EU countries for the main energy products (European Commission, 2013). Regarding the new regime, the European Commission (2011) document describes the 2011 EC's proposal.

Given the use of different sources and given the number of energy products, sectors, and countries considered, it is necessary to carry out some data transformations in order to have a coherent database.

Firstly, concerning the classification of energy products two main differences exist between the energy products taxed through the European ETD and those energy products available in the environmental accounts of the WIOD. The ETD regime distinguishes between products used as motor

[34] Croatia, member of EU from 2013, is not included in the analysis since WIOD covers the EU27. The 13 other countries are: Australia, Brazil, Canada, China, Indonesia, India, Japan, Korea, Mexico, Russia, Turkey, Taiwan, and Unites States.

[35] See the thesis Annex A for a more detailed description of WIOD database.

[36] The 26 energy products are further classified into six groups as following: coal (hard coal and derivatives, lignite and derivatives, coke); crude and feedstock (crude oil and feedstock); petroleum products (diesel oil for road transport, motor gasoline, jet fuel, light fuel oil, heavy fuel oil, naphtha, other petroleum products); gases (natural gas, derived gas); renewable and wastes (industrial and municipal waste, bio-gasoline including hydrated ethanol, bio-diesel, bio-gas, other combustible renewable); electricity and heat (electricity, heat, nuclear, hydroelectric, geothermal, solar, wind power, other sources).

[37] As defined in Genty et al. (2012), the non-energy use is the use of energy products as chemical feedstock (e.g. naphtha for plastic production), asphalt, lubricants, and solvents.

fuel and products used for heating,[38] but this distinction does not exist in WIOD database. Moreover, there is no a strict correspondence between the energy product classifications in the WIOD and in the ETD. For all these reasons, when necessary, data were integrated and transformed using additional information from the International Energy Agency – one of the primary source used to compile the environmental accounts of the WIOD – and from the database Odyssee (Odyssee-Mure, 2014). After all these transformations, nine uses of energy products are finally analyzed: gasoline (motor fuel), diesel (motor fuel), LFO, LPG (motor fuel), LPG (heating), natural gas (heating), HFO (heating), coal and coke (heating), and electricity. A detailed description of these transformations is shown in Appendix 3.A.

Secondly, as regards tax variation, the matrix **R** containing the variation in rates is filled in, considering in column the nine energy products analyzed, and in row 35 sectors for the 41 countries. The rate variation is assumed to be zero for all the non-EU, as well as, for those sectors in the EU countries that have a current rate higher than the new minimum proposed by the 2011 ETD reform.[39] Moreover, as it is summarized in Appendix 3.B, some sectors are treated in specific way in the new proposal. In particular we highlight three cases. For instance, to "electricity, gas and water supply" and "air transport", sectors already belonging to ETS and hence exempted from the tax component related to CO_2 emissions, it is also applied an exemption for the energy content component, so that the tax variation is equal to zero.[40] Another example is "agriculture", whose increase in taxation is especially greater because the reform tries to reduce favoured treatments (i.e. the elimination of previous exemptions for the energy tax component related to emissions). Finally, the reform also eliminates the favoured treatment for the commercial use of diesel: its

[38] The same tax rates are applied to heating use and to industrial use of energy products. For simplicity in the text we refer to heating use, although data refer to both categories.

[39] This seems to be a realistic assumption: if a country is already charging rates higher than the current minima proposed, there would be no reason for the proposal to cause an increase or a decrease in present rates. Anyway, this assumption could be changed in order to see what happens if other assumptions were implemented, for instance, that countries decided to lower the fiscal pressure at the minimum level required by the directive.

[40] Electricity is exempted because the most of products used by this sector are transformed in electricity. Air and water transport are exempted because they are regulated by international agreements.

enforcement would therefore cause a greater tax variation for the sector "inland transport".[41]

3.4. Results and discussion

3.4.1. Results

A simply descriptive analysis of the current level of taxation, the new tax rates proposed by the reform and the intensity of energy consumption in each country could shed some light on impact that the 2011 ETD reform would have had on costs and prices of the EU27 countries. However, such a partial analysis will not give a full insight into the effects on prices as it will not be taking into account the existing interactions between different sectors from different countries, which are crucial nowadays.

Table 3.3 shows the total effect (direct and indirect) on sectoral prices that the minimal rates proposed by the 2011 ETD reform would have had in the countries of the EU27. According to our estimation, the most remarkable aspect is that only the 5% of sectors (47 out of 945) would present a price increase higher than 0.50%. Obviously, in some cases small changes in prices could potentially cause important shifts in the origin and destination of traded goods and services. Then, to establish a threshold to determine if a price increase is weak (or not) is not evident at all and it might have a strong conventional component. Following Mongelli et al. (2010) we take 0.50% as a threshold and, for ease of reading, in Table 3.3 we mark cells with a higher value in grey. Moreover, following the proposal of Nguyen (2008) who compares his results with the inflation level of Vietnam, we also consider the threshold of 2% in the analysis of our results since the European Central Bank defined the price stability target for the EU as a variation of a year-on-year increase in the Harmonized Index of Consumer Prices (HICP) below this 2%.[42]

[41] The commercial use of energy products is defined by the current directive as the use for "the carriage of goods and the carriage of passengers" (European Council, 2003). In particular, countries that are currently applying this reduction are Belgium, Hungary, Italy, Spain, and Slovenia.

[42] See https://www.ecb.europa.eu/mopo/strategy/pricestab/html/index.en.html.

Table 3.3. Total effect on prices of the 2011 ETD reform

Sector		AUT	BEL	BGR	CYP	CZE	DEU	DNK	ESP	EST	FIN	FRA
1	Agriculture, Hunting, Forestry and Fishing	0.02	0.68	0.45	0.33	0.11	0.03	0.03	0.34	0.06	0.03	0.08
2	Mining and Quarrying	0.03	0.66	0.53	0.08	2.62	1.70	0.01	0.41	0.73	0.02	0.48
3	Food, Beverages and Tobacco	0.03	0.24	0.69	0.10	0.21	0.06	0.03	0.34	0.13	0.02	0.14
4	Textiles and Textile Products	0.04	0.21	0.68	0.06	0.20	0.05	0.03	0.30	0.08	0.02	0.09
5	Leather, Leather and Footwear	0.03	0.14	0.79	0.07	0.07	0.03	0.02	0.26	0.21	0.01	0.07
6	Wood and Products of Wood and Cork	0.03	0.21	0.64	0.05	0.12	0.05	0.02	0.23	0.07	0.02	0.07
7	Pulp, Paper, Printing and Publishing	0.03	0.09	0.36	0.02	0.06	0.02	0.01	0.13	0.03	0.02	0.03
8	Coke, Refined Petroleum and Nuclear Fuel	0.09	0.07	0.09	0.00	0.08	0.07	0.02	0.03	0.08	0.02	0.04
9	Chemicals and Chemical Products	0.05	0.40	1.53	0.08	0.99	0.09	0.02	0.59	0.32	0.03	0.24
10	Rubber and Plastics	0.05	0.27	0.54	0.08	0.14	0.04	0.03	0.47	0.05	0.02	0.11
11	Other Non-Metallic Mineral	0.04	0.11	0.34	0.03	0.16	0.08	0.02	0.16	0.08	0.02	0.05
12	Basic Metals and Fabricated Metal	0.03	0.08	0.31	0.03	0.11	0.03	0.02	0.11	0.03	0.02	0.03
13	Machinery, Nec	0.03	0.07	0.40	0.07	0.11	0.02	0.02	0.14	0.07	0.01	0.04
14	Electrical and Optical Equipment	0.02	0.11	0.32	0.06	0.05	0.02	0.02	0.15	0.03	0.01	0.04
15	Transport Equipment	0.03	0.11	0.28	0.08	0.10	0.03	0.02	0.15	0.04	0.01	0.05
16	Manufacturing, Nec; Recycling	0.03	0.23	0.52	0.05	0.08	0.03	0.02	0.19	0.08	0.01	0.08
17	Electricity, Gas and Water Supply	0.03	0.04	0.20	0.00	0.21	0.04	0.02	0.04	0.10	0.01	0.02
18	Construction	0.03	0.08	0.37	0.05	0.11	0.03	0.02	0.09	0.06	0.01	0.03
19	Sale, Maintenance and Repair of Motor Vehicles and Motorcycles	0.02	0.16	0.53	0.03	0.08	0.03	0.01	0.12	0.02	0.01	0.03
20	Wholesale Trade and Commission Trade	0.02	0.14	0.63	0.06	0.08	0.01	0.01	0.16	0.03	0.01	0.03
21	Retail Trade, Except of Motor Vehicles and Motorcycles	0.01	0.10	0.46	0.05	0.09	0.02	0.01	0.13	0.02	0.00	0.03
22	Hotels and Restaurants	0.01	0.14	0.49	0.09	0.11	0.03	0.01	0.11	0.04	0.01	0.06
23	Inland Transport	0.04	1.24	3.36	0.03	0.07	0.02	0.02	1.13	0.02	0.01	0.02
24	Water Transport	0.02	0.11	0.25	0.07	0.06	0.02	0.04	0.13	0.03	0.01	0.02
25	Air Transport	0.03	0.09	0.24	0.06	0.05	0.03	0.03	0.09	0.04	0.01	0.02
26	Other Supporting and Auxiliary Transport Activities	0.02	0.18	1.01	0.06	0.06	0.02	0.01	0.37	0.05	0.01	0.03
27	Post and Telecommunications	0.01	0.08	0.53	0.08	0.05	0.01	0.01	0.09	0.01	0.01	0.04
28	Financial Intermediation	0.01	0.05	0.16	0.02	0.05	0.01	0.00	0.04	0.01	0.00	0.02
29	Real Estate Activities	0.01	0.03	0.19	0.01	0.12	0.00	0.00	0.03	0.03	0.00	0.01
30	Renting of M&Eq and Other Business Activities	0.01	0.09	0.20	0.03	0.06	0.01	0.01	0.08	0.02	0.01	0.02
31	Public Admin and Defense; Compulsory Social Security	0.01	0.07	0.38	0.04	0.09	0.01	0.01	0.10	0.03	0.01	0.10
32	Education	0.01	0.05	0.50	0.01	0.15	0.01	0.00	0.07	0.02	0.00	0.04
33	Health and Social Work	0.02	0.07	0.53	0.06	0.12	0.02	0.01	0.09	0.02	0.01	0.03
34	Other Community, Social and Personal Services	0.01	0.12	0.50	0.05	0.13	0.01	0.01	0.12	0.02	0.01	0.05
35	Private Households with Employed Persons	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Unit: percentage. Note: For ease of reading, cells in grey mean sectors with a price variation higher than 0.50%.

EU27 countries: AUT: Austria; BEL: Belgium; BGR: Bulgaria; CYP: Cyprus; CZE: Czech Republic; DEU: Germany; DNK: Denmark; ESP: Spain; EST: Estonia; FIN: Finland; FRA: France; GBR: United Kingdom; GRC: Greece; HUN: Hungary; IRL: Ireland; ITA: Italy; LTU: Lithuania; LUX: Luxembourg; LVA: Latvia; MLT: Malta; NLD: Netherland; POL: Poland; PRT: Portugal; ROM: Romania; SVK: Slovak Republic; SVN: Slovenia; SWE: Sweden.

Source: own elaboration.

Table 3.3. (Continuation) Total effect on prices of the 2011 ETD reform

Sector		GBR	GRC	HUN	IRL	ITA	LTU	LUX	LVA	MLT	NLD	POL
1	Agriculture, Hunting, Forestry and Fishing	0.96	0.04	0.16	0.12	0.32	0.34	0.73	0.61	0.04	0.34	0.54
2	Mining and Quarrying	0.66	0.07	0.13	0.09	0.23	0.17	0.30	0.39	0.03	0.01	0.80
3	Food, Beverages and Tobacco	0.32	0.07	0.25	0.06	0.13	0.33	0.33	0.35	0.04	0.06	0.43
4	Textiles and Textile Products	0.30	0.08	0.11	0.04	0.08	0.28	0.34	0.28	0.04	0.03	0.20
5	Leather, Leather and Footwear	0.15	0.08	0.11	0.02	0.05	0.40	0.00	0.21	0.04	0.02	0.24
6	Wood and Products of Wood and Cork	0.15	0.09	0.15	0.05	0.04	0.44	0.13	0.30	0.04	0.02	0.42
7	Pulp, Paper, Printing and Publishing	0.06	0.04	0.06	0.02	0.03	0.11	0.09	0.07	0.03	0.02	0.14
8	Coke, Refined Petroleum and Nuclear Fuel	0.25	0.01	0.08	0.07	0.02	0.09	0.00	0.08	0.08	0.06	0.19
9	Chemicals and Chemical Products	0.33	0.16	0.24	0.03	0.14	0.20	0.35	0.30	0.07	0.05	0.74
10	Rubber and Plastics	0.15	0.08	0.14	0.04	0.06	0.10	0.25	0.14	0.05	0.05	0.24
11	Other Non-Metallic Mineral	0.03	0.04	0.09	0.04	0.04	0.06	0.11	0.10	0.03	0.04	0.14
12	Basic Metals and Fabricated Metal	0.07	0.04	0.06	0.04	0.03	0.08	0.08	0.06	0.02	0.02	0.14
13	Machinery, Nec	0.10	0.05	0.09	0.03	0.06	0.18	0.21	0.11	0.03	0.02	0.15
14	Electrical and Optical Equipment	0.06	0.06	0.05	0.02	0.06	0.15	0.21	0.12	0.03	0.02	0.14
15	Transport Equipment	0.10	0.05	0.07	0.02	0.04	0.15	0.17	0.15	0.02	0.03	0.15
16	Manufacturing, Nec; Recycling	0.10	0.09	0.10	0.09	0.04	0.19	0.55	0.19	0.03	0.02	0.21
17	Electricity, Gas and Water Supply	0.11	0.02	0.05	0.03	0.02	0.05	0.16	0.06	0.05	0.03	0.18
18	Construction	0.05	0.06	0.09	0.02	0.03	0.19	0.23	0.17	0.03	0.02	0.13
19	Sale, Maintenance and Repair of Motor Vehicles and Motorcycles	0.03	0.08	0.07	0.01	0.05	0.17	0.33	0.13	0.02	0.02	0.11
20	Wholesale Trade and Commission Trade	0.03	0.09	0.14	0.02	0.04	0.12	0.17	0.15	0.03	0.01	0.17
21	Retail Trade, Except of Motor Vehicles and Motorcycles	0.05	0.08	0.15	0.02	0.07	0.19	0.27	0.21	0.02	0.01	0.15
22	Hotels and Restaurants	0.10	0.04	0.18	0.02	0.08	0.24	0.42	0.21	0.03	0.02	0.18
23	Inland Transport	0.02	1.35	0.82	0.02	0.05	0.76	0.79	0.84	0.14	0.01	1.16
24	Water Transport	0.02	0.05	0.07	0.02	0.04	0.07	0.11	0.10	0.03	0.02	0.19
25	Air Transport	0.02	0.06	0.10	0.02	0.03	0.16	0.08	0.10	0.04	0.03	0.21
26	Other Supporting and Auxiliary Transport Activities	0.02	0.32	0.11	0.02	0.04	0.21	0.16	0.25	0.02	0.01	0.58
27	Post and Telecommunications	0.04	0.07	0.08	0.01	0.04	0.16	0.08	0.14	0.02	0.01	0.10
28	Financial Intermediation	0.02	0.02	0.06	0.01	0.02	0.08	0.05	0.05	0.02	0.01	0.09
29	Real Estate Activities	0.01	0.01	0.07	0.01	0.01	0.18	0.04	0.15	0.02	0.01	0.14
30	Renting of M&Eq and Other Business Activities	0.02	0.06	0.07	0.01	0.04	0.15	0.19	0.11	0.02	0.01	0.15
31	Public Admin and Defense; Compulsory Social Security	0.04	0.04	0.11	0.01	0.04	0.14	0.24	0.13	0.02	0.01	0.12
32	Education	0.03	0.03	0.11	0.01	0.02	0.28	0.26	0.18	0.02	0.00	0.10
33	Health and Social Work	0.06	0.06	0.13	0.02	0.04	0.25	0.31	0.20	0.03	0.01	0.12
34	Other Community, Social and Personal Services	0.03	0.04	0.12	0.01	0.05	0.19	0.27	0.18	0.03	0.01	0.19
35	Private Households with Employed Persons	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Unit: percentage. Note: For ease of reading, cells in grey mean sectors with a price variation higher than 0.50%.

EU27 countries: AUT: Austria; BEL: Belgium; BGR: Bulgaria; CYP: Cyprus; CZE: Czech Republic; DEU: Germany; DNK: Denmark; ESP: Spain; EST: Estonia; FIN: Finland; FRA: France; GBR: United Kingdom; GRC: Greece; HUN: Hungary; IRL: Ireland; ITA: Italy; LTU: Lithuania; LUX: Luxembourg; LVA: Latvia; MLT: Malta; NLD: Netherland; POL: Poland; PRT: Portugal; ROM: Romania; SVK: Slovak Republic; SVN: Slovenia; SWE: Sweden.

Source: own elaboration.

Table 3.3. (Continuation) Total effect on prices of the 2011 ETD reform

Sector		PRT	ROM	SVK	SVN	SWE
1	Agriculture, Hunting, Forestry and Fishing	0.09	0.17	0.08	0.03	0.01
2	Mining and Quarrying	0.21	1.90	1.63	0.14	0.01
3	Food, Beverages and Tobacco	0.21	0.20	0.19	0.09	0.02
4	Textiles and Textile Products	0.56	0.27	0.12	0.08	0.03
5	Leather, Leather and Footwear	0.19	0.25	0.13	0.06	0.02
6	Wood and Products of Wood and Cork	0.17	0.23	0.09	0.06	0.03
7	Pulp, Paper, Printing and Publishing	0.10	0.09	0.09	0.05	0.02
8	Coke, Refined Petroleum and Nuclear Fuel	0.01	0.27	0.07	0.04	0.03
9	Chemicals and Chemical Products	0.28	2.19	0.43	0.09	0.03
10	Rubber and Plastics	0.17	0.28	0.16	0.08	0.04
11	Other Non-Metallic Mineral	0.12	0.21	0.14	0.07	0.03
12	Basic Metals and Fabricated Metal	0.08	0.25	0.12	0.04	0.02
13	Machinery, Nec	0.12	0.25	0.08	0.05	0.02
14	Electrical and Optical Equipment	0.10	0.19	0.06	0.05	0.02
15	Transport Equipment	0.10	0.16	0.07	0.05	0.02
16	Manufacturing, Nec; Recycling	0.16	0.38	0.09	0.05	0.02
17	Electricity, Gas and Water Supply	0.04	0.28	0.09	0.04	0.01
18	Construction	0.11	0.14	0.06	0.05	0.02
19	Sale, Maintenance and Repair of Motor Vehicles and Motorcycles	0.10	0.25	0.07	0.05	0.01
20	Wholesale Trade and Commission Trade	0.14	0.10	0.06	0.04	0.01
21	Retail Trade, Except of Motor Vehicles and Motorcycles	0.14	0.12	0.11	0.03	0.01
22	Hotels and Restaurants	0.11	0.15	0.21	0.03	0.01
23	Inland Transport	1.68	0.53	0.53	0.89	0.02
24	Water Transport	0.10	0.11	0.07	0.02	0.02
25	Air Transport	0.10	0.09	0.09	0.02	0.02
26	Other Supporting and Auxiliary Transport Activities	0.25	0.30	0.18	0.11	0.05
27	Post and Telecommunications	0.06	0.12	0.08	0.02	0.01
28	Financial Intermediation	0.04	0.13	0.05	0.01	0.00
29	Real Estate Activities	0.02	0.10	0.15	0.01	0.01
30	Renting of M&Eq and Other Business Activities	0.09	0.16	0.06	0.02	0.01
31	Public Admin and Defense; Compulsory Social Security	0.11	0.10	0.11	0.01	0.01
32	Education	0.07	0.13	0.19	0.02	0.01
33	Health and Social Work	0.12	0.23	0.22	0.03	0.01
34	Other Community, Social and Personal Services	0.12	0.16	0.25	0.02	0.01
35	Private Households with Employed Persons	0.00	0.00	0.00	0.00	0.00

Unit: percentage. Note: For ease of reading, cells in grey mean sectors with a price variation higher than 0.50%.

EU27 countries: AUT: Austria; BEL: Belgium; BGR: Bulgaria; CYP: Cyprus; CZE: Czech Republic; DEU: Germany; DNK: Denmark; ESP: Spain; EST: Estonia; FIN: Finland; FRA: France; GBR: United Kingdom; GRC: Greece; HUN: Hungary; IRL: Ireland; ITA: Italy; LTU: Lithuania; LUX: Luxembourg; LVA: Latvia; MLT: Malta; NLD: Netherland; POL: Poland; PRT: Portugal; ROM: Romania; SVK: Slovak Republic; SVN: Slovenia; SWE: Sweden

Source: own elaboration.

Despite the country analyzed, 18 sectors would have a price variation lower than 0.50% due to the exceptions of the ETD reform, because they are already included in the ETS, or because their use of energy products is very low. These 18 sectors are: “pulp and paper” (7),[43] “coke and refined petroleum” (8), “other non-metallic minerals” (11), “basic metals” (12), “machinery” (13), “electrical and optical equipment” (14), “transport equipment” (15), “electricity, gas and water supply” (17), “construction” (18), “retail trade” (21), “hotels and restaurants” (22), “water transport” (24), “air transport” (25), “financial intermediation” (28), “real estate” (29), “renting and other business activities” (30), “public administration and defense” (31), and “private household with employed persons” (35). Sectors more affected by the reform across most EU Members States would be “mining and quarrying” (2), “chemicals and chemical products” (9), and “inland transport” (23). But even for these sectors the total impact on prices would be higher than 2% in only three countries: “inland transport” (23) in Bulgaria (3.36%), “mining and quarrying” (2) in Czech Republic (2.62%), and “chemicals and chemical products” (9) in Romania (2.19%).

A detailed analysis by country, sector and energy product reveals that there are two energy products – gasoline and electricity – for which countries are already applying tax rates that are generally higher than the minimum rates proposed by the reform and, in consequence, the reform would not actually cause an increase on prices.

As regards LPG, LFO and HFO, the analysis reveals that the quantity embodied in the production of goods is not relevant enough to affect prices significantly. Regarding LPG, the two countries that use it most intensively are France and United Kingdom: in France, the 36% of the industrial use of LPG corresponds to “chemicals” (9), while in United Kingdom the main users of LPG are “food” (3) (11%), “chemicals” (9) (19%), and “construction” (18) (20%). Anyway the price variation of these sectors never exceeds the 0.50%. As regards LFO, generally the main user is the sector of “agriculture” (1); in this case the total price variation is greater than the 0.50% in five countries: United Kingdom (0.96%), Luxembourg (0.73%), Belgium (0.68%), Latvia (0.61%), and Poland (0.54%). Finally, as regards HFO, this energy product is basically used by the sector “water transport” (24), which is regulated through international agreements and hence exempted by the ETD (and it would remain exempted also if the

[43] The number in parenthesis after a sector’s name refers to sectors’ number in Table 3.3.

reform were applied). Spain is the country that uses more intensively HFO, the 34% of the industrial use of this energy product is consumed by “electricity” (17), another of the sectors totally exempted by the ETD, which explains the non-existent increase on prices in this country.

The energy products that could cause higher impacts on prices in some countries are coal and coke, natural gas, and diesel. In particular, for coal and coke, the sectors mainly affected would be “mining and quarrying” (2), and “chemicals” (9). The main change that would influence “mining and quarrying” (2) is the increased tax rate on coal and coke (in particular for Belgium, Bulgaria, Czech Republic, Germany, Estonia, United Kingdom, Poland, Romania, and Slovakia); anyway the price growth never exceeds the 2%, with the exception of “mining and quarrying” (2) in Czech Republic. Although Poland, Germany, and France use coal and coke intensively and we would expect a higher price impact, the main sectors involved in these countries are partially or totally exempted for their inclusion in the ETS; these sectors are “other non-metallic mineral” (11), “basic metals and fabricated metals” (12), and “electricity” (17). For natural gas, the main sector affected would be “chemicals” (9) in Bulgaria and Romania, but also in this case the price increase is lower than 2%. For United Kingdom and Spain – the countries that most intensively use natural gas – the price increase for “chemicals” (9) would be 0.33% and 0.59%, respectively. Finally, the increase in diesel taxation would basically regard “inland transport” (23), in this case the price increase would be greater than 0.50% in 12 countries (Belgium, Bulgaria, Greece, Hungary, Lithuania, Luxembourg, Latvia, Poland, Portugal, Romania, Slovak Republic, and Slovenia) but only in the case of Bulgaria this increase would exceed the 2%.

All the previous results show that the ETD reform, if implemented, would have had different effects depending on sectors and countries. Even though many interest groups or lobbies might intervene in any political proposal, the ultimate agents that should approve (or not) the proposal are the political representatives of each country. The ETD reform should be approved by unanimity (see section 3.1.1) and thus, a global indicator of the effects on each country would be particularly relevant from the political point of view.

Taking into account the importance of countries in the decision of political processes, we now focus our analysis on the potential impact on prices for each country. A Laspeyres-type price index, as the computed by expression (3.1), summarizes all the price changes by country in an indicator of potential and maximum impact on consumers taking into account not only the effects on sectors but also the direct effect of taxation on energy products directly consumed by households. The second column of Table 3.4 shows the results for all the EU27 countries placing on the top of the table the countries less affected.

As Table 3.4 shows, our model estimates that the average effect on consumer prices for the EU27 countries would be 0.22%, which represents approximately one tenth of the price stability target for the EU27. For 24 countries the price index variation is lower than 0.50%. However, it is important to emphasize the great differences between countries, whose price index variations range from 0.02% to 0.71%; the coefficient of variation of the price index of the EU27 is equal to 0.89. The countries less affected would be Finland, Denmark, Sweden, Netherland, and Austria, mainly because they already apply rates that are generally higher than the minimum rates proposed by the 2011 ETD reform. In contrast the countries most affected would be Poland and Bulgaria, characterized by lower energy tax rates and by using more intensively the energy products more taxed, especially coal. Thus, even though the economic effects are moderate in any country, it is worth noting a difference between the negligible effects in some EU countries (mainly Nordic countries) and the more important effect for Eastern Europe countries.

Besides the price index variation, a proper way to quantify whether these changes in the consumer price indexes could be considered relevant or not is to compare the price index variation in relative terms with respect to the 2011 HICP for each country. This information is included in columns third and fourth of Table 3.4. Our results show that the increase in consumer prices would be a maximum of one fifth of the HICP in the case of Bulgaria; in other six countries (Czech Republic, Latvia, Hungary, Lithuania, Luxembourg, and Poland) it would exceed one tenth of the respective HICP.

Table 3.4. Price index change, EU27 countries

Country	Price index variation (1)	HICP 2011[a] (2)	Ratio (1)/(2)
Finland	0.02	3.3	0.01
Denmark	0.02	2.7	0.01
Sweden	0.03	1.4	0.02
Netherland	0.03	2.5	0.01
Austria	0.03	3.6	0.01
Germany	0.04	2.5	0.02
Cyprus	0.07	3.5	0.02
Slovenia	0.07	2.1	0.03
Malta	0.08	2.5	0.03
Greece	0.08	3.1	0.03
Italy	0.08	2.9	0.03
Estonia	0.09	5.1	0.02
Ireland	0.10	1.2	0.08
France	0.13	2.3	0.06
Portugal	0.20	3.6	0.06
United Kingdom	0.24	4.5	0.05
Slovak Republic	0.28	4.1	0.07
Spain	0.29	3.1	0.09
Belgium	0.29	3.4	0.09
Czech Republic	0.30	2.1	0.14
Romania	0.39	5.8	0.07
Latvia	0.42	4.2	0.10
Hungary	0.42	3.9	0.11
Lithuania	0.43	4.1	0.10
Luxembourg	0.59	3.7	0.16
Poland	0.61	3.9	0.16
Bulgaria	0.71	3.4	0.21
Mean[b]	**0.22**		
Coefficient of variation[c]	**0.89**		

Unit: percentage.
[a] HICP stands for Harmonized Index of Consumer Prices (data available at http://epp.eurostat.ec.europa.eu/tgm/table.do?tab=table&language=en&pcode=tec00118&tableSelection=1&footnotes=yes&labeling=labels&plugin=1)
[b] Mean is the arithmetic mean.
[c] Coefficient of variation is the ratio between the standard deviation and the mean.
Source: own elaboration.

All in all, the differences between countries are important to explain the conflicts that the different proposals on EU energy/carbon taxation have provoked since the early 1990s. The most ambitious initiatives – as the one in 1992 – failed due to the opposition of some governments. Nowadays, the difficulties to advance in environmental taxation are even higher in the EU28 and, probably, a compensation mechanism for countries more affected should be considered.

3.4.2. Discussion

There are two main characteristics of the ETD reform that, taken together, basically drive the results of our analysis: the way in which the rates are calculated as a sum of two different components, and the specific treatment for sectors belonging to the ETS.

As previously described, the ETD reform established minimum energy tax rates resulting from two different components. One component was linked to carbon emissions content and it did not depend on the different purposes the energy products are used for (20 €/tonCO2). The second component was linked to the energy content, and it was much lower for energy products used as heating or for industrial uses (0.15 €/GJ), higher for energy products used as motor fuels (9.6 €/GJ).

As regards sectors already belonging to the ETS, the plants participating to the emissions market would only be affected by the (very low) energy component and not by the CO_2 component to avoid "double burden". In this way the reform tried to create a consistent system of emissions control, considering both instruments in force, the energy tax and the ETS mechanism, and introducing a similar incentive to non-ETS and ETS sectors: all the sectors would pay the energy component, the non-ETS sectors would also pay the carbon component while the ETS sectors would take the allowances price into account when deciding to emit more or less CO_2.

Given the already high energy tax rates implemented in several EU countries – and on motor fuels in all the countries – and given the exemption of the ETS sectors to the tax related to CO_2 emissions, the main finding of our analysis is that the new energy tax regime would have a really low impact on prices, and this impact would regard few sectors in few countries. Although the proposal might not have a strong capability to change the production structure in order to reduce environmental pressures, it was an important step to introduce a taxation explicitly linked to CO_2 emissions, so explicitly shaped by environmental concerns.

Anyway, the reform was rejected. Considering our analysis, the reasons of this rejection are not so clear. However, it is important to bear in mind at least three possible reasons that our analysis is not taking into account. The first one has institutional nature: in the EU all the decisions on taxation requires the unanimity and this is very difficult to achieve. The second one is that the effects of a change in energy taxation affects very differently – even though in any case moderately – different sectors and countries. Last but not least, we should not underestimate the influence of some particular economic interests in political decisions – for instance the interests connected with coal sector or the industry of gasoline and diesel – even though they might have low weight in terms of total GDP or labor force.

Moreover, considering that the reform tried to coordinate energy tax and ETS, the discussion could go even farther. It would be interesting to know whether it would be appropriate to exclude from the ETD reform the ETS sectors, given the poor results shown by the ETS mechanism so far, as can be seen in Figure 3.1. Indeed, to establish a similar incentive for firms affected by the ETS and for firms affected by the energy tax, it would require to forecast with certain accuracy the CO_2 emissions price established through the market, while, as we have seen, the EU CO_2 market has been characterized by a great instability and very low prices, much lower than the reference value considered by the 2011 reform (20€/tonCO_2).[44] There are different policy options to reach a consistent price signal and to create a significant incentive to emissions reduction, although all of them are politically very difficult to be adopted. A possibility already analyzed in literature (Branger et al. 2013, Wood and Jotzo 2011) would be to establish some mechanism of price floor. Interestingly, Wood and Jotzo (2011) specifically propose an extra-fee (or tax) on carbon emitted, which suggests that the two instruments (emissions mechanism and tax) do not necessarily exclude each other.

In a way, considering the failure of ETS, it is questionable if the carbon taxation on ETS sectors should be considered as a substitute or a complement of the allowances market. For this reason, we simulate a different scenario to see what would happen if the 2011 ETD reform proposal did not exempt the ETS sectors from the 20€/tonCO_2 tax component. This is an extreme framework that can be justified only if we

[44] According to a 2012 EU Report (European Commission, 2012) several factors –mainly the economic downturn and the acquisition of cheap credits in carbon markets linked to CDM and JI Kyoto mechanisms– caused a great surplus of allowances and a dramatic reduction of prices. The situation did not change in 2013 when the price was typically around 4€/ tonCO_2 or even lower; in the first months of 2014 the prices has been situated between 4.5 and 7€/tonCO_2. The 2012 EU Report considered the supply-demand imbalance as a structural problem and several meetings are currently debating different ways to avoid the price collapse and the ETS failure.

suppose that the ETS market is suppressed, or it collapses to insignificant prices, or alternatively if the political target is assumed to be 20€/tonCO_2 as a floor price (to add to the uncertain allowance price). The potential impact on prices reveals the importance of maintaining a relevant carbon price incentive for the ETS sectors and it can serve as a point of reference for evaluating more moderate proposals.[45]

As expected, this second simulation leads to strongly different results. The main change would affect the electricity sector. In particular, for some eastern countries such as Estonia, Bulgaria, Poland, and Czech Republic, the imposition of the new taxation to the ETS sectors would imply an increase in the price of electricity equal to 24.30%, 21.06%, 11.78%, and 8.36% respectively. This is because these countries are highly dependent on coal and coke for electricity production. The most interesting result is that in comparison with the first scenario, in this second scenario the effect would not be limited to few sectors, but spread in several sectors of the economy. While the reform proposed in 2011 would cause a price increase greater than 0.50% for only the 5% of the total of sectors/countries considered, a tax also imposed to the ETS sectors would significantly affect roughly the 16% of the total sectors/countries considered.

Table 3.5 shows results by country. The second column of Table 3.5 displays the price index variation for the EU27 countries including the ETS sectors sorted in increasing order. When considering the ETS sectors, the price increase would rise, on average, from 0.22% (Table 3.4) to 0.65%. The countries less affected would be more or less the same but including France, probably due to the relative weight of nuclear power;[46] and the most affected would also be Poland and Bulgaria. In this case the price index variation would be greater than 0.50% for 15 EU countries. The great

[45] As in the previous analysis, the model not only assumes that taxes are completely translated into prices but it also assumes that there are not technical changes neither. This last assumption is particularly unrealistic when – as it is now the case – the relative prices changes considerably. Regarding the electricity sector, it is considered as any other ETS sector affected by the new minima taxes: although the most part of countries are now applying specific taxes on electricity and they could react to the new minima reducing these taxes, we have not taken this possible reaction into account.

[46] Taking into account the environmental risks of nuclear power, it could be argued that a European reform of energy tax should also introduce a specific tax on nuclear electricity. In fact the 1992 and 1995 European proposal for a CO_2 tax reform also introduced taxation for nuclear power (even though less than the fossil fuel taxation). Moreover, Padilla and Roca (2004) proposed that a new European CO_2 tax should be complemented by a high taxation for nuclear power.

differences between countries still persist (values ranges from 0.12% to 1.91%) although they are lower than before (the coefficient of variation of the price index for the EU27 countries is now 0.69). The third and fourth columns of Table 3.5 show the 2011 HICP and its relation with the price index variation for each country. In this case, the values are higher than in Table 3.4: only in three countries the increase in consumer prices would be lower than one tenth (Sweden, Austria, and France). In any case, however, the price increase would exceed the annual inflation.

Table 3.5. Price index change, EU27 countries, including ETS sectors

Country	Price index variation (1)	HICP 2011[(a)] (2)	Ratio (1)/(2)
Sweden	0.12	1.4	0.09
Austria	0.19	3.6	0.05
France	0.22	2.3	0.09
Netherland	0.27	2.5	0.11
Denmark	0.29	2.7	0.11
Italy	0.30	2.9	0.10
Finland	0.33	3.3	0.10
Germany	0.34	2.5	0.14
Ireland	0.35	1.2	0.29
Slovenia	0.44	2.1	0.21
Portugal	0.47	3.6	0.13
Spain	0.49	3.1	0.16
Greece	0.51	3.1	0.16
Belgium	0.51	3.4	0.15
United Kingdom	0.52	4.5	0.12
Cyprus	0.54	3.5	0.16
Malta	0.60	2.5	0.24
Slovak Republic	0.67	4.1	0.16
Latvia	0.72	4.2	0.17
Lithuania	0.72	4.1	0.18
Luxembourg	0.73	3.7	0.20
Hungary	0.87	3.9	0.22
Romania	0.92	5.8	0.16
Czech Republic	1.28	2.1	0.61
Estonia	1.53	5.1	0.30
Poland	1.60	3.9	0.41
Bulgaria	1.91	3.4	0.56
Mean[(b)]	**0.65**		
Coefficient of variation[(c)]	**0.69**		

Unit: percentage.

[(a)] HICP stands for Harmonized Index of Consumer Prices (data available at http://epp.eurostat.ec.europa.eu/tgm/table.do?tab=table&language=en&pcode=tec00118&tableSelection=1&footnotes=yes&labeling=labels&plugin=1)

[(b)] Mean is the arithmetic mean.

[(c)] Coefficient of variation is the ratio between the standard deviation and the mean.

Source: own elaboration.

The results of this second simulation are not realistic: they merely represent a hypothetical scenario. In this case, it should be considered how the demand for final goods and intermediate goods would react given the increase in prices that this scenario would lead. In any case, it seems interesting to include these results in the discussion to reinvigorate the debate on the potential of an energy tax, which seems to be effective as a political tool of emissions control, and an alternative to the emissions trading mechanism. Taking into account that the effects would have been much more important in all the countries, this result not only shows the complexity of introducing a general carbon tax, it also shows how difficult it is to adopt effective measures of emissions reduction and effective tools to foster a proper performance of the emissions market.

3.5. Conclusion

The analysis we have proposed is focused on the European ETD, an environmental taxation applied to energy products used by industrial sectors and by households. More specifically, in 2011 the EC proposed a renewal of the existing ETD, but in 2012 the proposal did not find the approval of the Parliament and the taxation in force is still the previous directive approved in 2003. The Parliament's main concerns regarded the possible effect of the proposal on prices and the negative impact on competitiveness.

Given this framework, the aim of this analysis was to estimate what potential economic effect the reform could have had on prices in the EU27 countries if implemented. We carried out a multi-region and multi-sector analysis and we used one of the latest available world input-output table: the one provided by the WIOD that offers information about the economic flows of 41 countries and 35 sectors.

The main finding of our first simulation was that the new energy tax regime would not have had a strong and wide impact on prices: the tax increase would have caused a price variation greater than 0.50% only for few sectors in few countries; expressing the price changes through a consumer price index, the effect of the reform would have been even weaker. Due to the characteristics of the model and the price index used these results are, indeed, the maximum effect on prices since there is not any substitution of any kind. Besides, these results were basically driven by the fact that the reform would have tried to coordinate energy taxation with ETS keeping sectors already belonging to the ETS exempted from the main component of taxation. Indeed, applying the reform also to ETS sectors, as in our second simulation, the results were strongly different showing a more relevant and wider impact on prices.

The results of this analysis entail three main policy implications. The first one is that the concerns about an important impact of the 2011 ETD reform on competitiveness and prices do not find empirical support in our results. The rejection of the reform might have been driven by other factors, such as the fear of feeding the long and deep economic crisis, or the belief of some countries that taxation matters should remain an exclusive competence of each State Member. Moreover, the shortage of studies on economic impact of the 2011 ETD reform might have led to unreasonably exaggerate this impact. This work aims at reducing this lack by using a world database, which is essential to take into account inter and intra-sectoral interdependences in the global supply chain.

Second, our outcomes also show that the impacts would have been different for different sectors and different countries. Thus, even when the aggregated economic impact was very weak, particular interests could have been significantly affected and they could have had important political influence. For some of the reform opponents, for instance, the attempt proposed by the 2011 ETD reform to balance the tax treatment of different energy products such as gasoline and diesel would have gone against previous policies aimed at fostering the research and use of diesel engines. While it is clearly necessary to take into account sectors or countries likely to be particularly affected by the reform and it might also be desirable to provide some compensation mechanism for them, it is equally true that development policies should not go against other European targets such as emissions control.

The third issue is the relationship between the two main instruments for emissions control put in place by the EU: energy taxation and ETS. Although avoiding a double burden is aimed at reducing distortions in the choices of economic agents, it is questionable whether the carbon taxation on ETS sectors should be considered as a substitute or a complement of the allowances market given the weaknesses of ETS's incentives nowadays. If we consider that the (potential) economic impact on prices is an indicator of the (potential) environmental impact, our results suggest the relevance of maintaining significant economic incentives to reduce carbon emissions, introducing in the ETS mechanisms to keep emissions market price higher or applying carbon taxation also to these sectors.

The ETS has been defined as one of the EU's flagship climate change project; to strengthen this instrument a future increase in the proportion of allowances auctioned is planned. However, the ETS has not been able to work properly due to the low prices of allowances. Perhaps it would be useful to consider alternatives, such as introducing a general European CO_2 tax – in the line proposed in the 1990s – or introducing other effective mechanisms to keep allowances prices higher. In the light of our analysis, the failure of the 2011 ETD reform does not seem in line with the role that the EU has set for itself with respect to climate change and emissions control.

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Appendices

Appendix 3.A. Energy data transformations

Table 3.A.1. Main transformations applied

Products
The main products that are taxed through the ETD are: petrol used as motor fuel; gas oil, kerosene, liquefied petroleum gas (LPG) and natural gas used as motor fuel as well as for heating; heavy fuel oil (HFO) and coal and coke used for heating; finally electricity. Biofuels are currently taxed but an option of fully exemption exists, and they would remain exempt under the reform. Nuclear fuels are not energy products for the purposes of the directive. For some of these products a correspondence exists between the ETD classification and the classification used in the WIOD database.
Product selection
Three uses - kerosene used as motor fuel, kerosene used for industrial use and heating, and natural gas used as motor fuel -are excluded from the analysis for the following reasons. As regards kerosene, it is used as motor fuel basically by the aviation sector that is exempted from the energy component of the tax for competitiveness reasons and is exempted from the CO_2 component of taxation because it is an ETS sector. As regards kerosene used as heating, when consumption is relevant, households rather than economic sectors basically use it. Finally, as regards natural gas used as motor fuel, it is not considered in the analysis because the IEA considers the amount consumed in most countries (except for Bulgaria, France, Germany, Italy, Sweden) as irrelevant, assigning to data (IEA, 2012a) a value equal to zero.
LPG
As regards LPG, two transformations are needed. Since in WIOD LPG is classified in the category “other petroleum products” along with other nine energy products (the products classified in the “other petroleum products” category are LPG, bitumen, ethane, lubricants, non-specified oil products, other kerosene, paraffin waxes, petroleum coke, refinery gas, white spirit.), it is necessary to desegregate the WIOD category into the different components. This is done using IEA energy balances information that have been used for computing the WIOD category “other petroleum products” (IEA, 2012a). Then, it is necessary to distinguish between LPG used as motor fuel and LPG used for heating. Also in this case the additional information used comes from IEA energy balances: in IEA data (IEA, 2012a) there is a final consumption flow named “road” that records fuels used in road vehicles. For LPG, as for gas oil and petrol, this flow has been split and allocated to all NACE sectors and private consumption in WIOD. Following the same procedure, explained in Genty et al. (2012), it is possible to desegregate, for each WIOD sector, the share of LPG classified in IEA as “road”, and consider this component as LPG used as motor fuel, while the remaining share of LPG is considered as used for heating. This transformation requires additional information from IEA prices (IEA, 2012b) and from the database Odyssee (Odyssee-Mure, 2014).
Coal and coke
The different WIOD products “coal” and “coke” are aggregated in a single product as in the ETD. Table 3.A.2 summarizes the correspondences between ETD and WIOD products and the transformation needed.
Conversion factors
It is necessary to convert WIOD energy data in units coherent with the ETD: in the ETD rates on different products are expressed in euro related to different volumetric measures. In particular: rates on petrol, gas oil and kerosene are expressed in euro per 1000 liters, rates on LPG are expressed in euro per 1000 kilograms, rates on natural gas, coal and coke are expressed in euro per gigajoule. On the other hand, WIOD energy use tables are expressed in their energy content (TJ). They have indeed to be conveniently transformed with the ETD (see Table 3.A.3).

Source: own elaboration.

Table 3.A.2. Correspondence between ETD and WIOD energy products classification

ETD product	WIOD product	Transformation
Petrol (motor fuel)	Gasoline	None
Gas oil (motor fuel)	Diesel	None
Gas oil (heating)	Light fuel oil-LFO	None
Kerosene (motor fuel)	Jet fuel	Excluded
Kerosene (heating)	Other kerosene	Excluded
LPG (motor fuel)	Other petroleum products	Desegregated
LPG (heating)	Other petroleum products	Desegregated
Natural gas (motor fuel)	Natural gas	None
Natural gas (heating)	Natural gas	Excluded
Heavy fuel oil-HFO (heating)	Heavy fuel oil-HFO	None
Coal and coke	Coal	Aggregated
Coal and coke	Coke	Aggregated
Electricity	Electricity	None

Source: own elaboration.

Table 3.A.3. Conversion factors

WIOD Energy Product	WIOD Units	ETD Units	Net Calorific Value (NCV, GJ/1000 kg) Density (D, Kg/m^3) Conversion factor (CF, GJ/1000 kg)	Transformation from WIOD to ETD Units
Gasoline (motor fuel)	TJ	1000 kg	CF=NCV= 32.8	Data in 1000 kg=TJ x 1000/32.8
Diesel (motor fuel)	TJ	1000 l	NCV =42.3; D=832; CF=NCV x D/1000=35.2	Data in 1000 l=TJ x 1000/35.2
LFO (heating)	TJ	1000 l	NCV=42.3; D =832; CF=NCV x D/1000=35.2	Data in 1000 l=TJ x 1000/35.2
LPG (motor fuel)	TJ	1000 kg	CF=NCV (GJ/1000 kg)= 46	Data in 1000 kg=TJ x 1000/46
LPG (heating)	TJ	1000 kg	CF=NCV (GJ/1000 kg)= 46	Data in 1000 kg=TJ x 1000/46
Natural gas (heating)	TJ	GJ		Data in GJ=TJ x 1000
HFO (heating)	TJ	1000 kg	CF=NCV (GJ/1000 kg)= 40	Data in 1000 kg=TJ x 1000/40
Coal-coke (heating)	TJ	GJ		Data in GJ=TJ x 1000
Electricity	TJ	MWh	CF=NCV (GJ/MWh)= 3.6	Data in MWh= TJ x 1000/3.6

Source: own elaboration from European Commission (2011).

Appendix 3.B. Tax variation matrix compiling

Table 3.B.1. Economic activities subject to the ETS and WIOD sectors

Economic activities	**WIOD sector**
Energy activities	
Combustion installations with a rated thermal input exceeding 20 MW (except hazardous or municipal waste installations)	Electricity, Gas and Water Supply
Mineral oil refineries Coke ovens	Coke, Refined Petroleum and Nuclear Fuel
Production and processing of ferrous metals	
Metal ore (including sulfide ore) roasting or sintering installations Installations for the production of pig iron or steel (primary or secondary fusion) including continuous casting, with a capacity exceeding 2,5 tons per hour *Mineral industry* Installations for the production of cement clinker in rotary kilns with a production capacity exceeding 500 tons per day or lime in rotary kilns with a production capacity exceeding 50 tons per day or in other furnaces with a production capacity exceeding 50 tons per day Installations for the manufacture of glass including glass fiber with a melting capacity exceeding 20 tons per day Installations for the manufacture of ceramic products by firing, in particular roofing tiles, bricks, refractory bricks, tiles, stoneware or porcelain, with a production capacity exceeding 75 tons per day, and/or with a kiln capacity exceeding 4 m3 and with a setting density per kiln exceeding 300 kg/m3	Basic Metals and Fabricated Metal
Other activities	
Industrial plants for the production of (a) pulp from timber or other fibrous materials (b) paper and board with a production capacity exceeding 20 tons per day	Pulp, Paper, Paper , Printing and Publishing
Aviation	
Flights which depart from or arrive in an aerodrome situated in the territory of a Member State to which the Treaty applies	Air Transport

Source: own elaboration from European Parliament and Council (2003, 2008).

Table 3.B.2. Specific treatment for some sectors

WIOD sector	**New minima applied (for all energy product)**
Agriculture, Hunting, Forestry and Fishing	Component related to CO^2 emissions
Pulp, Paper, Paper , Printing and Publishing	Component related to energy content
Coke, Refined Petroleum and Nuclear Fuel	Component related to energy content
Other Non-Metallic Mineral	Zero
Basic Metals and Fabricated Metal	Component related to energy content
Electricity, Gas and Water Supply	Zero
Inland Transport	Component related to CO^2 emissions (only for gas oil)
Water Transport	Zero
Air Transport	Zero

Source: own elaboration.

Chapter 4

The reform of the European Energy Tax Directive: does data disaggregation matter? The Italian case

4.1. Introduction[47]

In 2011, the European Commission (EC) proposed a reform of the current system of energy taxation, the European Energy Tax Directive (ETD) (European Commission, 2011a). Besides promoting energy efficiency and consumption of more environmentally-friendly products, the aim of the new ETD was to coordinate the environmental taxation with the Emissions Trading Mechanism (ETS), another market mechanism introduced by the Community in 2005, to establish a comprehensive and consistent CO_2 price signal outside the European Union (EU) ETS. However, the new proposal was blocked and the ETD 2011 reform was not applied, mainly due to worries about its effect in terms of competitiveness that some political and economic groups claimed.

In Chapter 3 we have explained in detail and analyzed the effect of the EC proposal to reform the ETD focusing on 27 countries belonging to the

[47] I thank Angelica Tundini, Giusy Vetrella, Renato Marra and Aldo Femia from the Italian National Statistical Institute to provide the database used.

EU. Complementing the previous work, we now focus on one specific country that is Italy.

Italy has indeed a quite peculiar position concerning environmental taxation. In 2007 the country introduced its current legislation (Italian Government, 2007) to implement the 2003 European ETD. This legislation places Italy halfway between the northern and the other southern European countries. The first ones typically implement higher energy taxation, while southern European countries are usually characterized by a lower environmental tax burden. Nowadays Italy has a relatively high level of energy taxation on diesel for transport and on heavy fuel oil (HFO) for heating and industrial use. However, the fiscal rates imposed on other energy products such as liquefied petroleum gas (LPG) or natural gas are below the 2011 ETD proposal. Moreover, Italy has recently expressed a commitment to increase the use of environmental taxation (Chamber of the Deputies and the Senate of the Republic, 2014). To review excise duties on energy products and electricity, the Parliament explicitly referred to the reform of the ETD proposed by the EC in 2011 (European Commission, 2011a).

Anyway, even if Italy stated the will to increase the use of energy taxes and did not oppose the reform proposed by the Commission in 2011, some economic agents declared a negative opinion against the reform and they called on the European Parliament and the Council to disassociate them from the proposed increase in taxation.[48]

Given that Italy is planning to introduce changes in the existing legislation considering the 2011 Commission proposal, the aim of this study is to analyze the effect that the 2011 ETD reform would have had in Italy, if implemented. In particular, this work tries to verify the robustness of the results previously found taking advantage of a detailed dataset on energy use obtained for Italy. Compared to the World Input-Output Database (WIOD) used in Chapter 3, the main advantage of the data obtained for Italy is that they offer information on energy use disaggregated in different

[48] Three major European automobile manufacturer associations ("Associazione Nazionale Filiera Industria Automobilistica" for Italy, "Comité des Constructeurs Français d'Automobiles" for France and "Verband der Automobilindustrie" for Germany) have issued a joint statement against the proposed increase in diesel taxation. The main claim was an expected negative impact on the European automobile market as the demand for diesel and gas car models would decrease considerably due to the increase in taxation. See National Association of the Automotive Industry et al. (2011).

purposes. For each economic sector and each energy product analyzed, they show what share has served for heating use, for transport use, and for other energy use with or without combustion. This data disaggregation fits the scope of our analysis. Since the reform proposed different levels of taxation depending on the use of energy products, the detailed database on energy use permits to avoid some transformations needed in the previous analysis.

However, since disaggregated data are available only for Italy, we carry out the analysis within a single-region framework. Single-region models were more frequently applied before multi-region databases were made available. Lately more comprehensive multi-region frameworks have substituted them, offering more reliable information about technological processes used to produce goods and services domestically and abroad. On the contrary a single-region framework assumes that products imported in a region have been produced using the same technology available in the region analyzed ("domestic technology assumption"). Anyway, in this analysis we use a single-region framework because it makes it possible to employ more detailed information on energy products use. The comparison between the results obtained in this analysis with the results previously obtained permits to show if the framework strongly biases the results, or if single-region models can still be a reliable instrument that permits to use information not available at a multi-region level.

Environmental taxes are largely analyzed as they are important as emissions control tools, and the literature on the topic is quite rich. Studies go from basic economic analyses on functions of abatement costs to analyses of more complex implications, such as the effects of environmental tax on competitiveness and the case of double dividend, or the tax incidence and the effects in terms of social welfare and redistribution.

Regarding Italy, Montini (2000) describes the relation between the Italian policies and the international legal framework such as the United Nations Framework Convention on Climate Change (UNFCCC) or the Kyoto Protocol. Besides this descriptive analysis, Tiezzi (2005) analyzes the effects of the Italian carbon tax introduced in Italy at the beginning of 1999. Using true cost of living index number and compensating variation, she studies the welfare effects and the distributive impact on Italian households. Although she finds substantial welfare loss, the redistribution does not reveal that the Italian carbon tax of 1999 was regressive.

Afterwards, Martini (2009) extended the work of Tiezzi, analyzing more in details different types of households and macro-regions, and she proposes additional policy scenarios. Bartocci and Pisani (2013), and Cingano and Faiella (2013) estimate the effects of possible carbon taxes on private transport. They use, respectively, a general equilibrium model and a hybrid model to find out the effect on energy demand, total emissions, and other macroeconomic implications. Both analyses find that the carbon tax would reduce emissions reducing the demand for private transport.

As far as we know, only Mongelli et al. (2009) estimate the effect of different carbon tax rates on prices at a sector level. They find that a carbon tax of 20 euro per ton of CO_2 would produce a modest increase in prices. Our analysis falls into this last research line, but unlike Mongelli et al. (2009) we do not propose hypothetical carbon taxes but we analyze the effects on prices that the 2011 ETD reform would have had in Italy if implemented, using detailed data about sectoral energy consumption. Moreover the comparison with the results obtained in Chapter 3 permits to verify if, in the case analyzed, a single-region model can be a good approximation of more realistic multi-region models.

After describing methodology and data in Sections 4.2 and 4.3, Section 4.4 shows the main results, and Section 4.5 concludes.

4.2. Methodology

In this analysis we consider one region with n sectors, each sector producing one product j. The total production cost for j depends on its inputs and its value added. The input-output table contains information about all region's inter-industry deliveries: in this table the j-th column shows the total value of the j-th industrial output as the sum of the production cost $x_j = \sum_{i=1}^{n} x_{ij} + v_j$, where x_j is the total j-th sector's output, x_{ij} is the input that the j-th sector needs from the i-th sector, and v_j is the value added.[49] In matrix terms, we have $\mathbf{x}' = \mathbf{A_t}\hat{\mathbf{x}} + \mathbf{v}'$, where $\mathbf{A_t}$ shows the

[49] Matrices are indicated by bold, upright capital letters; vectors by bold, upright lower case letters; and scalars by italicized lower case letters. Vectors are columns by definition, so that row vectors are obtained by transposition, indicated by a prime. A circumflex indicates a diagonal matrix with the elements of any vector on its diagonal and all other

technology of the region, whose elements are $a_{ij} = x_{ij}/x_j$. The single-region input-output model assumes that the region acts as a closed economy: matrix $\mathbf{A_t}$ shows the total input coefficients, considering both domestic and foreign inputs.

Post-multiplying by $\hat{\mathbf{x}}^{-1}$ and re-writing the expression, we obtain the cost per unit of output as $\mathbf{p}' = \mathbf{w}'(\mathbf{I} - \mathbf{A_t})^{-1} = \mathbf{w}'\mathbf{L_t}$, where $\mathbf{w}$ represents the cost of primary inputs per unit of output and $\mathbf{p}$ is the price vector in which each price is indexed and equal to 1. The price vector depends on primary input cost and on the Leontief matrix $\mathbf{L_t}$ derived from the matrix of total input coefficients $\mathbf{A_t}$.

Whenever an additional cost per unit value of output $\mathbf{t}$ is added, a new price vector is considered; then the new price would be defined by $\tilde{\mathbf{p}}' = (\mathbf{w}' + \mathbf{t}')\mathbf{L_t}$. The increase in prices is given by the difference between the new prices vector and the old one: $\Delta\mathbf{p}' = (\mathbf{t}')\mathbf{L_t}$.

The analysis considers the increased energy taxation as additional cost. So, regarding the new cost $\mathbf{t}$, it is necessary to work out the additional tax per unit of product that each sector would have faced if the reform proposal had been implemented. Given this aim, it is necessary to know, for each sector, the consumption of the different energy products per unit of output, and the additional taxation on each energy product. So, vector $\mathbf{t}$ is computed as, $\mathbf{t} = (\mathbf{D} \circ \mathbf{R})$ where $\mathbf{D}$ is a matrix of coefficients of energy use by energy product and by purpose, $\mathbf{R}$ is a matrix of tax rates variations, i is a column vector of appropriate dimension, and $\circ$ is the element-wise product of matrices $\mathbf{D}$ and $\mathbf{R}$. In particular, $\mathbf{D}$ is obtained considering a matrix $\mathbf{E}$ of energy flows disaggregated by purpose from energy-producing sectors to all sectors and considering the output $\mathbf{x}$ produced by each sector $\mathbf{D} = \mathbf{E}\hat{\mathbf{x}}^{-1}$.

As for the analysis at the EU level, we compare the cost of the basket of goods that characterizes households' consumption before the implementation of the new energy tax with the cost of the same basket after the reform. This price index W takes into account that the EU energy tax reform also applies to energy products consumed directly by households:

entries equal to zero. The notation $\mathbf{i}$ is used to represent a column vector of 1's of appropriate dimensions.

$$W = \frac{\sum_{i=1}^{n} \tilde{p}_i q_i + \sum_{e=1}^{m} t_e q_e}{\sum_{i=1}^{n} p_i q_i} \tag{4.1}$$

Being q_i the quantity of goods and services i consumed by households, p_i the initial price of the commodity i, $\tilde{p}_i$ the new price after the proposal implementation, t_e the tax variation of each energy product e applied to households' consumption, and q_e the quantity of each energy product consumed by households.

4.3. Data description

To analyze the effects of the 2011 ETD reform in Italy three databases have been used.

First, economic information on Italian productive system is available in the Italian input-output tables (ISTAT, 2011).[50] We use the year 2008 as an approximation of 2011. [51]

Second, to work out the additional tax per unit of product that each sector would have faced we use information regarding the present tax rates applied in Italy (European Commission, 2011b)[52] and the environmental tax rates proposed by the 2011 ETD reform (European Commission, 2011a).

Finally, the matrix of energy use coefficients is derived using the energy use tables estimated by the Italian National Statistical Institute (ISTAT).[53] In particular, as regards the industrial use of energy products, the analysis takes advantage of detailed information recorded by ISTAT: indeed, the institute compiles three-dimensional energy use tables annually. These tables provide data about intermediate and final consumption of energy,

[50] See the thesis Annex A for a detailed description of ISTAT input-output tables system.
[51] When the following analysis was done, the year 2008 was the last available for both input-output tables and energy use data.
[52] As for Italy, the information is updated to August 2011. The database refers to the legislative decree 504 of 1995 (Italian Government, 1995), updated in 2007 (Italian Government, 2007). These acts are the implementation of the Council Directive of 2003 96/EC (European Council, 2003; European Parliament and Council, 2003), directive restructuring the Community framework for the taxation of energy products and electricity.
[53] These tables are not published, but for this study we obtained from ISTAT the energy use table related to 2008.

desegregated by energy product,[54] by activity[55] and by purpose. More in detail, purposes are classified in three main blocks: energy use with combustion, energy use without combustion, and non-energy use. These blocks are further divided as Table 4.1 shows.

Table 4.1. ISTAT classification by purposes in the energy use tables

Purposes		Production activities	Households
Energy use with comb.	Heating use	Heating (office building, factory, …)	Heating (home)
	Road transport use	Road transport carried out both as principal and secondary activity and as ancillary activity (own account)	Road transport by households (own account)
	Off-road transport use	Railway, air and maritime transport as well as all operations of ships, boats, tractors, construction machinery, lawn mowers, military and other equipment	Off-road transport by household (mainly operations of boats and lawn mowers)
	Transf. in electricity	Energy products used to produce electricity (transformation in electricity)	
	Other energy use with combustion	Energy products used in production processes (excluding heating, transport and transformation)	Energy products used for cooking and for hot water
Energy use without combustion		Energy products used to produce other energy products (transformation in energy products different from electricity); use of electricity for all purposes	Use of electricity for all purposes
Non-energy use		Energy products used to produce non-energy products (transformation in non-energy products); energy products used for non energy purposes (degreasing, dry cleaning,…)	Energy products used for non energy purposes (degreasing, lubrication,…)

Source: Femia et al. (2011).

As explained in Femia et al. (2011), there are three main advantages in using these data. The first advantage is that data are recorded following the principle of residents units and this is consistent with national accounts and input-output tables. Second, the three-dimensional split of the tables avoids the "double counting" typical of datasets expressed in gross terms where data are not classified in different purposes. Finally, this three-dimensional data desegregation (by sector, energy product and purpose) fits the scope of

[54] Energy products comprise 27 types: coal, lignite, peat, natural gas, crude oil, waste, electricity, coke, coke oven gas, non-energy coal products, gas work gas, blast furnace gas, LPG, refinery gas, naphtha, motor gasoline, aviation gasoline, jet fuel, kerosene, diesel oil, fuel oil, petroleum coke, white spirit, bitumen, lubricants, chemical products, ETBE. Each product is expressed in terajoules (TJ).

[55] As regards activities, tables record data regarding household as well as production activities that are classified using the NACE classification. In particular, up to the year 2008, the used classification is the NACE Rev 1.1, that is the same classification used for the input-output tables available.

the analysis since the ETD and its reform propose different rates depending on the purpose the energy product is used for.

Given the different sources used, it is necessary to transform some data to have a coherent database. Since data on the consumption of energy products are classified by industry, and the environmental taxation is applied to industry consumption of energy products, we estimate an "industry-by-industry" input-output table of 57 sectors.

Data are then selected depending on the scope the reform is expected to have in Italy. Regarding the energy products, the 2011 ETD reform would have caused an increase in the tax rates for LPG, kerosene, gas oil, natural gas and fuel oil. In the same way, we only consider the purposes that the reform would have affected, that is, heating use, motor fuels and other energy use with combustion. In this case, the main transformation is the conversion of energy data recorded by ISTAT in units coherent with the European taxation directive (European Council, 2003), the Commission proposal (European Commission, 2011a) and the environmental taxation database (European Commission, 2011b). Appendix 4.A, Table 4.A.1 describes the different units and the conversion factors applied.

Finally, we need to estimate the tax rate variation that the 2011 ETD reform would have caused in Italy.[56] To this purpose, we compare the current and the proposed rates (see Appendix 4.A, Table 4.A.2) taking into account the current Italian situation regarding rates and exemptions (see Appendix 4.A, Table 4.A.3) and the different treatment for sectors already belonging to the other economic mechanism of emissions control, the ETS (see Appendix 4.A, Table 4.A.4). For these sectors reduced rates should be permitted since only the energy component of the tax would have been applied.

4.4. Results

Table 4.2 describes the effects on prices that the 2011 ETD reform would have caused in Italy. The table shows, first, the direct additional cost the reform would imply for each sector (columns 1 to 4) and then its total cost taking into account all the sectoral interdependencies. (columns 5 to 8). In

[56] As we did in Chapter 3, when the new minimum proposed is lower than the present rate no change in taxation is assumed.

both cases, the analysis considers three different effects separately: tax changes related to transportation use (columns A), tax changes related to heating use (columns B) and finally tax changes that regard other energy use with combustion (columns C).

Considering the direct additional cost the reform would have, the two sectors mainly affected would have been the "manufacture of textiles" (10)[57] and "chemicals" (17), with a price increase equal to 0.18% and 0.15% respectively.

Table 4.2. Effects on prices of the 2011 ETD reform in Italy

		Direct effect				Total effect			
	Sector	**A**	**B**	**C**	**TOT**	**A**	**B**	**C**	**TOT**
1	Agriculture, hunting	0.00	0.00	0.01	**0.01**	0.01	0.01	0.03	**0.05**
2	Forestry	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.00**
3	Fishing and fish farms	0.00	0.00	0.00	**0.00**	0.01	0.00	0.01	**0.02**
4	Mining of coal and lignite, extraction of peat	0.00	0.00	0.00	**0.00**	0.01	0.01	0.02	**0.04**
5	Extraction of crude petroleum and natural gas and incidental services	0.00	0.00	0.00	**0.00**	0.00	0.00	0.01	**0.01**
6	Mining of metal ores	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	**0.01**
7	Other mining and quarrying	0.00	0.00	0.05	**0.05**	0.01	0.00	0.07	**0.08**
8	Manufacture of food products and beverages	0.01	0.02	0.06	**0.09**	0.03	0.03	0.10	**0.16**
9	Manufacture of tobacco products	0.00	0.00	0.01	**0.01**	0.00	0.00	0.02	**0.02**
10	Manufacture of textiles and textile products	0.01	0.02	0.15	**0.18**	0.02	0.03	0.22	**0.27**
11	Manufacture of wearing apparel	0.00	0.00	0.01	**0.01**	0.01	0.01	0.08	**0.10**
12	Manufacture of leather and leather products	0.00	0.00	0.02	**0.02**	0.01	0.01	0.06	**0.08**
13	Manufacture of wood and wood products	0.00	0.00	0.03	**0.03**	0.02	0.01	0.05	**0.08**
14	Manufacture of pulp, paper and paper products	0.00	0.00	0.00	**0.00**	0.01	0.01	0.03	**0.05**
15	Publishing, printing and reproduction of recorded media	0.00	0.03	0.01	**0.04**	0.01	0.03	0.03	**0.07**
16	Manufacture of coke, refined petroleum products and nuclear fuel	0.00	0.00	0.00	**0.00**	0.00	0.00	0.02	**0.02**
17	Manufacture of chemicals and chemical products	0.01	0.01	0.13	**0.15**	0.03	0.02	0.21	**0.26**
18	Manufacture of rubber and plastic products	0.00	0.03	0.02	**0.05**	0.01	0.04	0.08	**0.13**
19	Manufacture of glass; Manufacture of other non-metallic mineral products	0.00	0.00	0.00	**0.00**	0.01	0.00	0.02	**0.03**

Unit: percentage.

Notes: (A) Only tax changes related to transportation use; (B) Only tax changes related to heating use; (C) Only tax changes that regard other energy use with combustion; (TOTAL) All three changes together.

Source: own elaboration.

[57] The number in parenthesis after a sector's name refers to sectors numbers in Table 4.2.

Table 4.2. (Continuation) Effects on prices of the 2011 ETD reform in Italy

		Direct effect				Total effect			
	Sector	**A**	**B**	**C**	**TOT**	**A**	**B**	**C**	**TOT**
20	Manufacture of basic metals	0.01	0.00	0.00	**0.01**	0.02	0.01	0.03	**0.06**
21	Manufacture of fabricated metal products, except machinery and equipment	0.01	0.00	0.03	**0.04**	0.02	0.01	0.05	**0.08**
22	Manufacture of machinery and equipment	0.00	0.01	0.01	**0.01**	0.01	0.02	0.03	**0.06**
23	Manufacture of office machinery and computers	0.00	0.00	0.01	**0.01**	0.01	0.01	0.03	**0.05**
24	Manufacture of electrical machinery and apparatus n.e.c.	0.00	0.01	0.01	**0.01**	0.01	0.01	0.03	**0.05**
25	Manufacture of radio, television and communication equipment and apparatus	0.00	0.01	0.01	**0.02**	0.01	0.01	0.03	**0.05**
26	Manufacture of medical, precision and optical instruments, watches and clocks	0.00	0.00	0.01	**0.01**	0.01	0.01	0.03	**0.05**
27	Manufacture of motor vehicles, trailers	0.00	0.03	0.01	**0.04**	0.02	0.04	0.05	**0.11**
28	Manufacture of other transport equipment	0.00	0.01	0.01	**0.01**	0.01	0.01	0.04	**0.06**
29	Manufacturing of furniture, manufacturing	0.00	0.00	0.01	**0.01**	0.01	0.01	0.04	**0.06**
30	Recycling	0.00	0.00	0.01	**0.01**	0.01	0.01	0.04	**0.06**
31	Electricity, gas, steam and hot water supply	0.00	0.00	0.00	**0.00**	0.01	0.00	0.01	**0.02**
32	Collection, purification and distribution of water	0.00	0.00	0.00	**0.00**	0.01	0.00	0.02	**0.03**
33	Construction	0.00	0.00	0.00	**0.00**	0.01	0.00	0.02	**0.03**
34	Sale, maintenance and repair of motor vehicles; retail sale of automotive fuel	0.01	0.00	0.00	**0.01**	0.01	0.01	0.02	**0.04**
35	Wholesale trade and commission trade, except of motor vehicles and motorcycles	0.00	0.00	0.00	**0.00**	0.01	0.01	0.01	**0.03**
36	Retail trade, except of motor vehicles; repair of personal and household goods	0.01	0.00	0.00	**0.01**	0.02	0.01	0.02	**0.05**
37	Hotels and restaurants	0.01	0.01	0.00	**0.02**	0.02	0.01	0.03	**0.06**
38	Transport via railways; Other land transport and transport via pipelines	0.07	0.00	0.00	**0.07**	0.07	0.00	0.01	**0.08**
39	Water transport	0.00	0.00	0.00	**0.00**	0.02	0.01	0.02	**0.05**
40	Air transport	0.00	0.00	0.00	**0.00**	0.01	0.01	0.02	**0.04**
41	Supporting and auxiliary transport activities	0.00	0.00	0.00	**0.00**	0.01	0.01	0.01	**0.03**

Unit: percentage.

Notes: (A) Only tax changes related to transportation use; (B) Only tax changes related to heating use; (C) Only tax changes that regard other energy use with combustion; (TOTAL) All three changes together.

Source: own elaboration.

In both cases, the increment is due to the tax change related to the consumption of natural gas for industrial uses with combustion rather than transport or heating. The rest of sectors are not (or practically not) directly affected by the 2011 ETD reform. In fact, the increase in production costs would represent less than 0.1% increase for the 53% of sectors, and close to 0 for the remaining 44%.

However, industries use energy products to produce goods and services, but they also use intermediate products that need energy to be produced. So, when one sector increases its production costs due to a higher taxation on energy products consumed, this extra cost could be passed on (totally or partially) to other sectors. Taking into account such interdependencies and assuming that sectors fully pass on the cost increase, the results show a different picture (see the remaining columns of Table 4.2). The percentage of sectors that are almost not affected by the reform decreases from 44% to 9%. On the other hand, besides "manufacture of textiles" (10) and "manufacture of chemicals" (17), four new sectors present a price increase bigger than 0.1%. These are "manufacture of food" (8), "manufacture of wearing apparel" (11), "manufacture of rubber and plastic products" (18), and "manufacture of motor vehicle" (27).

However, in any case the increase in prices would not be greater than 0.35%. So, even in the most costly scenario,[58] the European tax reform would have meant a negligible cost to final consumers. Considering the representative basket of goods and services consumed by households, its cost after the tax reform would increase only by a 0.08%. In 2011 the variation of the consumption price index was equal to 2.8% (ISTAT, 2012), so the reform would keep it almost unchanged.

Finally, we compare the results obtained in this analysis with the results obtained in Chapter 3. There are two main differences between the two analyses. First, they employ different data on the use of energy products by sector. Second, they use a different methodological framework: a multi-region input-output model and a single-region input-output model. In particular, this second analysis employs more disaggregated data on energy use but it approximates technological processes considering all the inputs as they were produced domestically. Comparing the results we show if the approximations applied strongly biases the outcome of the analysis.

There are four sectors that show different results in the different analysis: "agriculture, hunting and forestry", "mining and quarrying", "textiles and textile products", and "chemicals and chemical products". For the first two sectors the analysis with a single-region model would imply a price variation lower than the one found in the previous analysis. The price

[58] We assume that all sectors fully pass on their cost to the last buyer, and hence the consumer bears the full cost increase of the 2011 ETD reform. In that way, we obtain a synthetic measure to approximate the maximum effects that the tax reform would have had on Italian consumers.

variation for “agriculture, hunting and forestry” would be, on average, 0.03% with a single-region model, 0.32% with a multi-region model. For “mining and quarrying” the two percentages would be, respectively, 0.04% and 0.23%. Conversely, in the case of “textiles and textile products”, and “chemicals and chemical products” the price variation when we apply the single-region model (0.27% and 0.26% respectively) is higher than the price variation obtained through a multi-region model (0.08% and 0.14% respectively). A possible reason could be that for these sectors a relatively important part of inputs is imported from abroad. In this case the DTA might bias the results more. However, this explanation fits more for chemical products. In fact the sector imports roughly the 30% of its inputs. In this case the single-region model might overestimate the effect of the reform since it applies to all imports the same tax increase of the domestic products. The other three sectors use instead mostly domestic inputs (the 85% of total inputs are domestic), so it is not possible to draw the same conclusion. Another reason could instead be that for these sectors the type of use of energy products is particularly relevant to the outcome of the analysis. To know more in detail what of the two reasons is the most important we would need to apply a multi-region framework with detailed data on energy use, but data are not available.

Anyway, considering all the sectors analyzed, the outcome is similar. For the most part of sectors, the difference between the prices variations obtained under the two models is less than 0.05%. The price index found using the two frameworks is, in both cases, 0.08%. So, except for some specific sectors, we can conclude that the approximations applied in the two analyses do not invalidate the results.

4.5. Conclusion

Since Italy has recently expressed a commitment to increase the use of environmental taxation by explicitly referring to the amendments proposed by the EC in 2011, in this work we offer empirical evidence on the effect that the 2011 ETD reform would have had in Italy, if implemented, considering all the industry interdependences. The analysis complements the proposal of Chapter 3 by using a more disaggregated dataset on the energy products used by economic sectors. Anyway, since data are available only for Italy, their use makes it necessary to employ a single-region model. This model assumes that all inputs are produced with the technology available domestically. On the one hand the results of this analysis might be more reliable since we employ more disaggregated data on energy use. On the other hand the method used approximates the production processes for imported goods.

Results shows that both considering only the direct effect of the reform on prices and considering the sectoral interdependences, only few prices would be affected and the variation in prices would be irrelevant for almost all sectors. The main conclusion of our analysis is that the new energy tax regime might have a really low impact on Italian prices, and consequently there might be no problem for competitiveness and distributional implication. On the other hand, this implies a low capability of this reform to cause an improvement in consumption and production patterns regarding environmental pressure.

Since these results are not enclosed in a general equilibrium framework, neither any input substitution nor any supply-demand interaction is considered. Nonetheless, what this static analysis does show is the maximum effect that this reform would have had in Italy if implemented. Even in the extreme situation of non-substitution and non-interaction between supply and demand, the maximum increase in prices would be lower than 0.3% and for Italian consumers the cost would be negligible (roughly a 0.08% variation in consumption price index). These results are under the assumption of non-substitution, that is, neither firms nor consumers can change the amount of inputs/products consumed. So, although one could argue that it is necessary to introduce further analyses (for instance, the analysis of products' demand elasticity) the expected results would be even smaller.

Regarding the comparison with the results previously found, in general the two analyses provide similar outcomes. A possible conclusion is that single-region model can be still a useful instrument if they make it possible the use of more disaggregated data available only for one or few countries. Anyway, this conclusion might be case-specific. In fact in the comparison we cannot recognize what role data disaggregation and what role the framework used have in influencing the results. The use of a single-region model might be complemented with other information to check its reliability. Finally, although results are similar, this is not the case for some specific sectors, such as: “agriculture, hunting and forestry”, “mining and quarrying”, “textiles and textile products”, and “chemicals and chemical products”. This result suggests the need of further analyses specifically applied to these sectors.

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Appendices

Appendix 4.A. ETD, reform, and Italian rates

Table 4.A.1. Energy data

Energy data transformation
In the legislative sources rates on different products are expressed in euro related to different volumetric measures. In particular: rates on petrol, gas oil and kerosene are expressed in euro per 1000 liters (l), rates on LPG are expressed in euro per 1000 kilograms (kg), rates on natural gas, coal and coke are expressed in euro per gigajoule. On the other hand, Italian data on energy use by sector are expressed in their energy content (terajoule, TJ). The European Commission makes available conversion factors for each energy product (documentation ancillary to the Commission proposal (European Commission 2011a)

Conversion factors for energy products

Energy product	ISTAT Units	ETD Units	Net Calorific Value (NCV, GJ/1000 kg) Density (D, Kg/m^3) Conversion factor (CF, GJ/1000 kg)	Transformation in ETD units
LPG	TJ	1000 kg	CF=NCV = 46	1000 kg= TJ x 1000/46
Kerosene	TJ	1000 l	NCV=43.8; D=810; CF=NCV x D/1000=35.5	1000 l= TJ x 1000/35.5
Gas oil	TJ	1000 l	NCV=42.3; D=832; CF=NCV x /1000=32.8	1000 l=TJx1000/32.8
Fuel Oil	TJ	1000 kg	CF=NCV= 40	1000 kg= TJx1000/40

Source: European Commission (2011a).

Table 4.A.2. Minima rates in the 2003 ETD and minima rates in the 2011 reform

	Current minima	Minima proposed in ETD reform		
		Energy content	CO_2 emissions	Total
Motor fuels		**(9.6 €/GJ)**	**(20 €/ton)**	
Petrol (€ per 1000 l)	359	314	46	360
Gas oil (€ per 1000 l)	330	337.9	52.1	390
Kerosene (€ per 1000 l)	330	340.6	50.9	392
LPG (€ per 1000 kg)	125	442	58	500
Natural gas (€ per GJ)	2.6	9.6	1.1	10.7
Heating fuels and motor fuels for industrial use		**(0.15 €/GJ)**	**(20 €/ton)**	**Total**
Gas oil (€ per 1000 l)	21	5.28	52.1	57.37
Heavy fuel oil (€ per 1000 kg)	15	6	61.84	67.84
Kerosene (€ per 1000 l)	0	5.32	51	56.3
LPG (€ per 1000 kg)	0	6.9	58	64.86
Natural gas (€ per GJ)	0.15	0.15	1.12	1.27
Coal and coke (€ per GJ)	0.15	0.15	1.89	2.04
Electricity				
Electricity (€ per MWh)	0.5	0.54	--	0.54

Source: European Council (2003) and European Commission (2011a).

Table 4.A.3. Actual tax rate applied in Italy

Petrol (per 1,000 litres)		
Leaded	571.30	
Unleaded	571.30	
Gas oil (per 1,000 litres)		
Propellant use	430.30	
Industrial/Commercial use	126.90	
Heating	403.21	
Kerosene (per 1,000 litres)		
Propellant use	337.49	
Industrial/Commercial use	101.25	
Heating	337.49	
Heavy fuel oil (per 1,000 kg)		
Heating - Business use	63.75(>1)/31.39(<1)	
Heating - Non-business use	128.27(>1)/64.24(<1)	
Liquid Petroleum Gas (LPG) (per 1,000 kg)		
Propellant use	227.77	
Industrial/Commercial use	68.33	
Heating	189.94	
Natural Gas (per gigajoule)		
Propellant use	0.078	
Industrial/Commercial use	0.32	
Heating - Business use	0.3378	
Heating - Non-business use	1.189(-120mc/y)/4.729(120-480mc/y)/ 4.594(480-1560mc/y)/ 5.027(1560-mc/y)/	
Coal		
	per gigajoule	**per 1,000 kg**
Heating - Business use	0.16	4.60
Heating - Non-business use	0.32	9.20
Coke		
	per gigajoule	**per 1,000 kg**
Heating - Business use	0.16	4.60
Heating - Non-business use	0.32	9.20
Lignite		
	per gigajoule	**per 1,000 kg**
Heating - Business use	0.16	4.60
Heating - Non-business use	0.32	9.20
Electricity		
	per MWh	
Business use	3.10	
Non-business use	4.70	

Source: European Commission (2011b).

Table 4.A.4. Sectors subject to the ETS

Economic activities	**WIOD sector**
Energy activities	
Combustion installations with a rated thermal input exceeding 20 MW (except hazardous or municipal waste installations)	Electricity, Gas and Water Supply
Mineral oil refineries Coke ovens	Coke, Refined Petroleum and Nuclear Fuel
Production and processing of ferrous metals	
Metal ore (including sulfide ore) roasting or sintering installations Installations for the production of pig iron or steel (primary or secondary fusion) including continuous casting, with a capacity exceeding 2,5 tons per hour	
Mineral industry	
Installations for the production of cement clinker in rotary kilns with a production capacity exceeding 500 tons per day or lime in rotary kilns with a production capacity exceeding 50 tons per day or in other furnaces with a production capacity exceeding 50 tons per day Installations for the manufacture of glass including glass fiber with a melting capacity exceeding 20 tons per day Installations for the manufacture of ceramic products by firing, in particular roofing tiles, bricks, refractory bricks, tiles, stoneware or porcelain, with a production capacity exceeding 75 tons per day, and/or with a kiln capacity exceeding 4 m3 and with a setting density per kiln exceeding 300 kg/m3	Basic Metals and Fabricated Metal
Other activities	
Industrial plants for the production of (a) pulp from timber or other fibrous materials (b) paper and board with a production capacity exceeding 20 tons per day	Pulp, Paper, Paper , Printing and Publishing
Aviation	
Flights which depart from or arrive in an aerodrome situated in the territory of a Member State to which the Treaty applies	Air Transport

Source: own elaboration from European Parliament and Council (2003) and European Parliament and Council (2008).

Chapter 5

Carbon-motivated border tax adjustment: a proposal for the EU

5.1. Introduction[59]

The threat of climate change caused by air emissions is a global problem that requires global instruments to address it. The absence of a commitment to implement tools on a global scale has been one of the major difficulties in reaching an international agreement since the Kyoto Protocol, and it is one of the main limits to the policies implemented so far.

In this context, there is currently an important debate regarding carbon-motivated border tax adjustment (CBTA). CBTA is a trade instrument that consists of tariffs on imported products applied by countries that are implementing local policies to reduce emissions (hereinafter abating regions). CBTA is designed to remedy the main drawback of unilateral emissions control: emissions reduction policies applied only locally create a

[59] A previous version of this Chapter was originally published as working paper in UB Col·lecció d'Economia (2015), E15/327. It was presented to the XXII International Input-Output Conference (México D.F., 2015), to the XI Biennial Conference of the European Society for Ecological Economics (Leeds, 2015), and to the VI Spanish Conference of Input-Output Analysis (Barcelona, 2015). I thank the participants for useful comments that help to improve this work. I also thank Iñaki Arto for his suggestions on the use of COMEXT database, Christoph Böhringer, Joshua Elliott, Aadytya Mattoo, Dominique van der Mensbrugghe, and David Weisbach for their helpfulness.

gap between the price of domestic and foreign products that compete in the same market. To level out different treatments for domestic and foreign goods, or – to use a recurring expression – to "level the carbon playing field" (Houser et al., 2008; Krugman, 2009), CBTA tariffs would be imposed on products imported from all countries that are not applying a carbon control policy (hereinafter non-abating regions). This would compensate for the loss of competitiveness that a carbon tax might imply for domestic producers, and it would avoid possible emissions leakage involved in unilateral emissions reduction policies (Lockwood and Whalley, 2010; Horn and Sapir, 2013).[60]

The viability of this tool has already reached the political agenda of regions like the United States (US) and the European Union (EU) (Mattoo et al., 2009; Kuik and Hofkes, 2010). In 2009, the US government proposed implementing an emissions trading mechanism, the American Clean Energy and Security Act (American House of Representatives, 2009).[61] Although ultimately the act was not approved, the proposal included border adjustment as a competitiveness measure to ensure the equal distribution of costs in the absence of an international agreement limiting emissions. In the same year, the EU also expressed worries about possible carbon leakage caused by the EU Emissions Trading Scheme (ETS). In the revised ETS directive (European Parliament and Council, 2009), the EU evaluated the inclusion of importers in the scheme. Moreover, international trade authorities such as the World Trade Organization (WTO) have already considered the relevance of CBTA (see UNEP and WTO, 2009; Hillman, 2013).

However, CBTA has not been implemented thus far. Its application might be difficult due to the several issues to which it gives rise. These include, for example, the compatibility of CBTA with the international legal framework established by the WTO, which countries and products should be involved, and how non-abating regions would respond to such a tax on their imports.

[60] To provide a better justification for CBTA, Horn and Sapir (2013) refer to international externalities that arise when countries combat emissions unilaterally. Indeed, countries implementing a unilateral climate policy face the full costs of their abatement efforts, receiving only part of the benefits that are spread across the world. As a result, they will typically choose sub-optimal climate policies, exposing each other to more climate damage than would be internationally efficient, that is, exposing each other to international externalities.

[61] The American Clean Energy and Security Act was a US energy bill that, if also approved by the Senate, would have established an emissions trading mechanism similar to the EU Emission Trading Scheme.

In particular, in this paper we focus on the CBTA metric, or – in other terms – what criteria should be applied to compute emissions related to imported products. Tariffs can be computed through different methods. One method is to compute the tariffs based on the emissions contained in each imported product, taking into account the technology and resources actually used to produce them. We call this method CBTA on embodied emissions. Alternatively, the tariff could be based on the emissions embodied in the same good produced by the abating region, as if the foreign product had been produced with the technology available domestically. We call this method CBTA on avoided emissions.

The debate revolves around three implications of these different metrics. The first implication is its compatibility with the WTO legal framework. The WTO regulation detailed by "GATT 1994" permits import duties not in excess of those applied to similar domestic products (Mattoo et al., 2009; Hillman, 2013). Therefore, tariffs calculated on avoided emissions are more justifiable as a trade policy. The second dimension is the political feasibility in terms of practical implementation. In this case also it is easier to implement CBTA on avoided emissions because it implies no discrimination among exporting countries. Moreover it requires less information on the emissions embodied in imported products. The third dimension is the environmental effectiveness of CBTA. While CBTA on embodied emissions is based on the actual emissions content of each product, CBTA on avoided emissions might be less effective as an environmental policy as it would not give any incentive for exporting countries to implement more environmentally friendly technologies.

Focusing on the different methods of designing a CBTA system, in this paper we analyze the extent to which the two CBTA metrics would variously affect different products imported from different countries. In particular, we assume a unilateral carbon tax implemented in the EU, and we simulate a corresponding CBTA system to show the different tax rates that each metric implies. We use a multi-region and multi-sector analysis to determine for which countries and products the method used is critical. The results of this paper might contribute to the political debate by adding information on the different effects for different products and countries.

There is already a vast literature on CBTA (see Ghosh et al., 2012, for a survey). Some papers analyze and compare different metrics for computing CBTA tariffs, although they do not consider all the connections among sectors and countries that characterize the production processes nowadays and that also determine emissions. Mathiesen and Maestad (2004), Kuik and Hofkes (2009), and Lin and Li (2011) consider only direct emissions of different sectors through the sectoral emissions intensity. Alternatively, Burniaux et al. (2013) consider the sum of direct emissions and emissions embodied in sectors' electricity use.

Instead, other papers take into account countries' and sectors' interconnections to determine CBTA rates, but they do not offer a comparison between different policy designs. Atkinson et al. (2011) focus on emissions embodied in domestic production and emissions embodied in consumption. Dissou and Eyland (2011) analyze different CBTA recycling methods. Ghosh et al. (2012) focus on efficiency and the distributional consequences of CBTA calculated only on CO_2 emissions or CBTA calculated on different greenhouse gases (GHGs). Finally, Schenker et al. (2013) analyze CBTA in terms of output variation, the welfare effect, carbon leakage, and trade composition.

To date, only three papers – Mattoo et al. (2009), Böhringer et al. (2012), and Elliott et al. (2013) – have considered both issues together: they compare different CBTA designs taking into account all inter-country and inter-sector interdependencies. In particular, Mattoo et al. (2009) assess the different impact of CBTA based on non-abating regions' emissions and CBTA based on abating regions' emissions. They consider several non-abating regions,[62] assuming unilateral emissions reductions of 17% by 2020 in high income countries (the EU, the US, Japan, and other United Nations Framework Convention on Climate Change (UNFCCC) Annex-I countries). They use a computable general equilibrium model based on 2004 data from the Global Trade Analysis Project (GTAP). The main finding is that CBTA on non-abating regions' emissions implies average tariffs for India and China of over 20%, and depresses manufacturing exports by between 16% and 21%. Moreover, CBTA on abating regions' emissions addresses the competitiveness problems without incurring so much damage for exporting countries.

Böhringer et al. (2012) compute the efficiency impact of different CBTA designs, analyzing three different regulating coalitions: Europe, UNFCCC Annex-I regions except for Russia, and a broad coalition that includes China. They simulate a unilateral cap at 80% of the abating regions' emissions. CBTA varies among three dimensions: embodied carbon coverage (direct, direct and electricity-related, or total emissions),

[62] High income countries, except for the abating regions Brazil, China, India, Russia, the rest of East Asia, the rest of South Asia, the rest of Europe and Central Asia, the Middle East and North Africa, sub-Saharan Africa, the rest of Latin American countries.

sector coverage (energy-intensive trade-exposed goods, or all goods), tariff rate differentiation (country- and sector-specific, or sector-specific tariffs). Using 2004 GTAP data, they find that systems more likely to comply with international law yield very little in terms of carbon leakage and efficiency.

Elliott et al. (2013) analyze the extent of emissions reduction for a wide range of carbon tax schemes for countries of the Kyoto Protocol Annex-B, the expected carbon leakage, and the effect of CBTA. They simulate both CBTA on embodied emissions and CBTA on emissions related to production technologies in importing countries. Using 2004 GTAP data through a computational general equilibrium model, they show the importance of global taxes: carbon taxes only in countries of the Kyoto Protocol Annex-B have low potential to reduce emissions. They also find that CBTA on abating regions' emissions can be significantly inferior in terms of reducing emissions compared to CBTA on non-abating regions' emissions. This is mainly due to the lack of incentives for foreign producers to adopt less-polluting technologies.

Our work follows the proposal of these three papers, with some differences. First, they focus on the broad effects of CBTA in terms of output, competitiveness or environmental goals using computational general equilibrium models. Instead, we propose a static analysis to show what tax level each policy design would imply at a product-based and at a country-based level. In this way, the analysis provides different information. It shows not only the intensity of different CBTA metrics through the average effect for each country, but also the spread or concentration of CBTA designs among different products of different countries, thus providing additional information to assess the feasibility of this policy.

Second, we focus in particular on the EU due to its position on carbon pricing. The EU debate on pricing carbon emissions has a long history dating back to the early 1990s. Moreover, the EU is already implementing different policies for emissions control, such as the ETS and the European Energy Tax Directive (ETD), a tax on the use of energy products aimed at reducing emissions. However, the main policies implemented so far are still weak or poorly performing.[63] For this reason, there are ongoing political debates regarding strengthening them to reach the challenging

[63]The European ETD currently in force fixes very low tax rates for the greater part of fuel uses and does not explicitly tax energy products according to their carbon emissions; looking at the ETS, during the last few years the carbon price has been too low to give a strong price signal (European Parliament and Council, 2009).

environmental targets the EU has set for its member states.[64] Despite the political difficulties in advancing carbon taxation in the EU, we believe it is important to revive the debate on implementing a harmonized EU carbon tax as a powerful climate change tool to reduce emissions. As CBTA is already feared for its potential in complementing a carbon tax, it seems important to analyze all the critical issues that this would imply, among them what method should be used to compute CBTA.

Third, as we take into account emissions embodied in trade flows, where previous studies have used the GTAP database we employ the World Input Output Database (WIOD), which is better suited to the scope of our analysis.

Finally, we also explore additional methodological issues that arise from the use of multi-region multi-sector models to compute the different CBTA regimes. In this Chapter we suggest the need to consider avoided emissions to compute CBTA based on emissions related to the abating regions' technology. Indeed, if tariffs are computed considering only (direct and indirect) emissions produced domestically, the fiscal load applied to foreign products would be lower than the fiscal treatment for domestic products: due to the adoption of CBTA, domestic goods would indeed be taxed based on their avoided emissions, the imported inputs also being taxed. So, to compute avoided emissions for analyzing border tax based on domestic technology, we apply the so-called "domestic technology assumption" (DTA).

Concerning the use of DTA, a second issue arises regarding international price differences. As analyzed in Arto et al. (2014), the usual way of estimating emissions according to the DTA could significantly bias the outcomes. The implicit assumption usually applied is that prices of imported goods are equal to prices of the same products produced at home. For this reason, in this paper we estimate avoided emissions correcting for the differences in prices of imported and domestically produced goods using trade data in physical units.

The Chapter is structured as follows. Section 5.2 describes the methodology and Section 5.3 the data used for the analysis. Results are introduced in Section 5.4. Finally Section 5.5 concludes.

[64] In addition to the ETS Directive, in 2001 the European Commission proposed to modify the ETD to introduce an explicit carbon tax component (European Commission 2011).

5.2. Methodology

A CBTA is a tax on the emissions of products imported by any region or country to compensate for different carbon policies (and especially carbon taxes) on products from different origins that compete in the same market. The tax base of this tariff can be calculated in two ways. The first method, the so-called CBTA on embodied emissions, takes into account the fact that production processes are often global and emissions produced in each stage of production are produced in different places; it accounts for all emissions embodied in imports. The second method, the so-called CBTA on avoided emissions, takes into account emissions contained in an identical hypothetical product produced entirely in the abating region or country; in this way it accounts for emissions avoided by importing goods.

Let us consider an example: the EU imports cans of tuna from Taiwan. This tuna has been fished in Korea, using boats and fishing rods produced in Japan. Emissions embodied in a can of tuna include not only emissions in Korea but also those in Japan. Alternatively, emissions avoided in the EU by importing cans of tuna from Taiwan are the emissions that the EU would emit fishing the tuna and producing the can, the boat, and the rods inside the EU.

We use an environmentally extended multi-regional input-output (MRIO) model to calculate emissions embodied in imports. In this case, let us consider a world consisting of c countries, each composed of n sectors.[65] Matrix $\mathbf{X}$ represents the inter-country inter-sector deliveries in the world, where its element x_{ij}^{rs} shows the amount of output from sector i in country r consumed as intermediate input by sector j in country s. Matrix $\mathbf{A}$ represents the world input structure, where each element a_{ij}^{rs} is obtained as $a_{ij}^{rs} = x_{ij}^{rs}/x_j^s$, x_j^s being the total output of sector j in country s. $\mathbf{A}$ permits the definition of the Leontief inverse $\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1}$, where any element l_{ij}^{rs} reveals additional direct and indirect output that sector i of county r produces for an additional monetary unit of sector j in country s. An environmentally extended MRIO adds information on emissions intensity e_i^r obtained by dividing total emissions by sector over total output produced

[65] Matrices are indicated by bold, upright capital letters; vectors by bold, upright lower case letters; scalars by italicized lower case letters. Vectors are columns by definition, so that row vectors are obtained by transposition, indicated by a prime. A diagonal matrix with the elements of any vector on its main diagonal and all other entries equal to zero is indicated by a circumflex. The notation $\mathbf{i}$ is used to represent a column vector of 1's of appropriate dimensions.

by each sector. Using this additional information, we compute $\mathbf{G} = \hat{\mathbf{e}}\mathbf{L}$, where any element g_{ij}^{rs} reveals the emissions that sector i of country r produces for an additional unit of sector *j* in country s.

Then, we re-allocate emissions by sector to emissions by product, taking into account that each sector can produce different products and also that any product can actually be produced by different sectors. Coming back to the previous example, let us consider that the Taiwanese cans of tuna are made of aluminum. These cans are mainly produced by the aluminum-processing sector. Imagine that in Taiwan some firms from the manufactured food sector buy cans, whereas other firms buy aluminum and make the cans themselves as a secondary mode of production. To apply the CBTA to imported cans of tuna, the EU needs to know the emissions embodied in each can of tuna that crosses from Taiwan to the EU, regardless of whether the can has been produced by the aluminum-processing sector or by the manufactured food sector. So, we use a rectangular matrix $\mathbf{U}$ of dimension [(*n* x *c*) x (*m* x *c*)] to link the information at the sector level to different products m. $\mathbf{U}$ is a diagonal block matrix, where u_{ik}^{rs} shows the share of product *k* of country *s* produced by sector *i* in country *r*. Finally, emissions embodied in any product are obtained as a (m x c)-dimensional vector $\tilde{\mathbf{e}}$ equal to $\tilde{\mathbf{e}} = \mathbf{i'GU}$.

A similar procedure is necessary for emissions avoided by importing goods. In this case, we use an environmentally extended single-region input-output model, applying the DTA. We calculate the amount of emissions that would have been contained in a domestic product if all its inputs were produced with the technology available domestically in region R. So, emissions by sector per unit of output are represented by $\mathbf{G_R} = \widehat{\mathbf{e_R}}\mathbf{L_R}$, where $\mathbf{e_R}$ is the vector of emissions intensities for region R and $\mathbf{L_R}$ is the Leontief inverse derived from the matrix of total input coefficients of the region $\mathbf{A_T}$, which includes domestic and imported inputs.

Since output is expressed in monetary terms, when we aggregate domestic and imported inputs to compute the matrix of total input coefficients $\mathbf{A_T}$ we need to take into account price differences across countries (see Arto et al., 2014). Each imported product k is therefore deflated using the ratio between foreign and domestic price p_k^s/p_k^r. As before, emissions by product are calculated as $\tilde{\mathbf{e}}_\mathbf{R} = \mathbf{i'G_R U_R}$, where $\mathbf{U_R}$ is a (n x m) matrix showing the share of any product *k* produced by any sector *i* of the region.

Finally, we obtain the tariffs $\boldsymbol{\tau}$ by multiplying the tax rate t that the region applies to the carbon content of domestic products multiplied by the emissions per monetary unit of imported product ($\tilde{\mathbf{e}}$ and $\tilde{\mathbf{e}}_{\mathbf{R}}$ depending on the method used) For emissions embodied in imports, we simply have $\boldsymbol{\tau} = t\tilde{\mathbf{e}}$, whereas the equivalent for emissions avoided by importing goods needs further consideration. Expressing tariffs per monetary units, we need again to deflate the results obtained to take into account price differences across countries. In this way, we obtain the CBTA on avoided emissions $\boldsymbol{\tau}_{\mathbf{R}}$ as: $\boldsymbol{\tau}_{\mathbf{R}} = \left(\frac{p_k^s}{p_k^r}\right) t\tilde{\mathbf{e}}_{\mathbf{R}}$.

Continuing with our example, let us assume that the EU fixes a domestic carbon tax rate t equal to 20 euros per ton of CO_2 (20€/tonCO_2). Let us also assume that the emissions to produce tuna cans in the EU are equal to 5 tons of CO_2 per thousand euro produced. So, the carbon tax applied to EU tuna cans would be equal to 0.1 per monetary unit (a 10% tax). If the EU tuna can price p_{tuna}^{EU} is 10 euros, the tax applied to each can of tuna is 1 euro. A CBTA on avoided emissions applies to foreign products the same fiscal treatment as to domestic products. In our example, this means imposing a tariff equal to 1 euro on each can of tuna imported from abroad. If the Taiwanese tuna can price p_{tuna}^{TAI} is 5 euros, the tariff per monetary unit is 0.2 instead of 0.1. In general terms, we apply a deflator per each product and each foreign country to express tariffs per monetary units.

5.3. Data description

The analysis requires information from two databases: the WIOD database, available since April 2012 and updated in November 2013 (WIOD, 2012, 2013), and the COMEXT database made available by Eurostat (Eurostat, 2015).

From the WIOD database we use a multi-regional input-output table, international supply and use tables, and CO_2 emissions data. We use the multi-regional input-output table at current prices for the year 2009.[66] This industry by industry table offers information in monetary terms (millions of US dollars) for 41 countries (27 countries of the EU, 13 other major countries in the world, and all the remaining regions aggregated in a single "rest of the world" region), and 35 sectors. This table is needed to compute

[66] See thesis Annex A for a detailed description of the WIOD database.

the emissions embodied in foreign products in the MRIO model. Second, we use the international supply and use tables for the same year to compute avoided emissions applying the environmentally extended input-output model. In this case, we aggregate the 27 countries of the EU into one single region, the EU27, using the information from the other 14 countries to determine the intermediate imports disaggregated by sector. We also use the international supply and use tables to obtain information desegregated by product, and compute the matrices $\mathbf{U}$ and $\mathbf{U_R}$. This information is available for 59 CPA products. For CO_2 emissions data, we employ the environmental accounts always from the WIOD. These satellite accounts have the same sector breakdown (35 sectors) and geographical coverage (41 countries) as the world input-output tables. In particular, from the air emissions accounts, we use data on CO_2 emissions (in 1000 tons) desegregated by sector.

From the COMEXT database we use data on international trade, recorded following the 2002 CPA classification. The COMEXT database contains statistics on trade among EU countries, and between EU member states and global partners. Data are available for 283 trading partners and 881 product categories, and they are expressed in monetary terms (euro) as well as in physical terms (kilograms). In particular, we use the information on the 14 non-EU countries available in the WIOD, and information on 217 products[67] to calculate the deflators and obtain CBTA on avoided emissions.[68]

5.4. Results

In this Chapter we consider the EU as a single region. Assuming that the EU has a domestic carbon tax, we simulate a hypothetical CBTA that the EU would apply on products imported from non-EU countries to "level the field." We use 2009 as the reference year.

In the simulation, first, we assume that the EU has a domestic carbon tax equal to 20 euros per ton of CO_2 emitted applied to all sectors. This tax level is realistic as it was in fact the tax rate proposed but not approved by the European Commission to reform the European ETD (European

[67] See Appendix 5.A for a complete list of the 217 products used from COMEXT.

[68] Appendix 5.B explains in detail how deflators are computed. It also shows the importance of using the highest data desegregation available to avoid biases in the deflators obtained. Appendix 5.C provides the deflators obtained.

Commission, 2011; Rocchi et al., 2014). Although we set the carbon taxation at a specific value to interpret our results more easily, the analysis could be expressed in a general form for any tax level *t*.[69] Second, we assume that non-EU countries are not implementing any emissions reduction policy.[70] Finally, we assume that the EU applies a CBTA on products imported from non-EU countries to compensate for the domestic carbon tax, without considering further emissions reduction policies the EU could be implementing.

The CBTA rates are calculated by product. Although the WIOD data are disaggregated in 59 different categories, we focus our analysis on only 22 manufactured products.[71] We exclude services considering CBTA as a system of customs duties applied to products physically imported. Regarding agricultural products and raw materials, the EU is unlikely to have all the resources to produce domestically all agricultural products and raw materials. Instead, it imports some goods that it does not produce. The disaggregation available in the data does not make it possible to distinguish between products that the EU is importing but also producing domestically from products that the EU does not have and therefore needs to import from abroad. As CBTA tariffs would be imposed on products that have an equivalent good produced domestically to level out different fiscal treatments applied to domestic and foreign goods, we exclude agricultural products and raw materials from the analysis.

The structure of this section is as follows. In Section 5.4.1 we compare at a global level the CBTA system computed following the two methods proposed: rates based on embodied emissions and rates based on avoided emissions. Then, we present the analysis at the product level and at the country level in Sections 5.4.2 and 5.4.3 respectively.

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[69] As tax rates are a linear transformation of the emission content of each product, rates in a general form can be obtained by multiplying the results obtained by *t*/20. Other duties would not change the comparison between countries and sectors found.

[70] If foreign countries already apply carbon policies, some compensation should be applied. Moreover, the literature suggests that, in a CBTA system, the abating regions could also exempt their exports from the domestic carbon taxation to avoid the competitive disadvantage of domestic firms in the world market (Holzer, 2010). However, this policy option is outside the scope of our analysis.

[71] The rates shown in this analysis are average tariffs, assuming a unique homogeneous good for each WIOD classification. Each WIOD category aggregates a wide variety of products. For this reason, starting from the results found in this analysis, a possible extension of this work could be a more desegregated analysis focused on the products that would incur the highest charges under a CBTA scheme. However, this is not possible with WIOD data, which permit instead a multi-regional analysis.

5.4.1. CBTA on embodied emissions and CBTA on avoided emissions

Table 5.1 shows CBTA rates by product, comparing rates computed on embodied emissions (white columns) and rates computed on avoided emissions (grey columns) for each non-EU country. Rates are computed per monetary unit imported. Thus, tax rates on embodied emissions vary by country because each country has a different technology and a different price for each product. Although emissions avoided by the EU when it imports a product are the same independently of the country from which the product is imported, tax rates computed considering avoided emissions also vary among countries due to international differences in prices.

To give a first overall picture, we compare the two different tax designs considering all the products and all the countries. The results in aggregate terms are displayed in Figure 5.1 in which we distinguish between products that would be more strongly affected through tariffs higher than 2%, products that would be mildly affected (with tariffs between 1% and 2%), and products less affected (with tariffs lower than 1%).

As expected, CBTA tariffs would be higher in a system based on embodied emissions (Figure 5.1a) in which rates would be more than 2% for 41% of the totality of the 308 products considered, more than twice as much as the products heavily taxed in a system calculated on avoided emissions (Figure 5.1b). A similar number of products would be mildly affected (42% and 32% respectively) under the two systems, whereas many more products would pay low tariffs under a system based on avoided emissions.[72]

[72] Appendix 5.D provides a similar comparison of the results obtained for a system based on avoided emissions, considering data in monetary terms without price adjustment, or deflating data to take into account international differences in prices; the comparison shows the bias that would result from not considering international price differences.

Table 5.1. Tariffs on embodied emissions and tariffs on avoided emissions, by product and by country, 2009

Product		AUS		BRA		CAN		CHN		IDN		IND		JPN	
		Embodied emissions	Avoided emissions	Embodied emissions	Avoided emissions	Embodied emissions	Avoided emissions	Embodied emissions	Avoided emissions	Embodied emissions	Avoided emissions	Embodied emissions	Avoided emissions	Embodied emissions	Avoided emissions
15	Food products and beverages	1.1	1.0	0.7	1.6	1.0	0.5	2.0	0.6	0.9	1.8	3.7	0.8	0.6	0.3
16	Tobacco products	1.1	0.8	0.7	2.3	1.0	0.4	2.0	0.5	0.9	3.8	3.7	3.0	0.6	1.4
17	Textiles	1.2	0.7	0.6	1.2	1.2	1.5	2.8	2.1	3.8	2.5	3.8	1.6	0.8	0.5
18	Wearing apparel	1.1	0.7	0.6	1.0	1.0	0.4	2.8	1.5	3.8	1.0	3.8	1.4	0.8	0.2
19	Leather and leather products	1.1	1.8	0.5	0.9	0.9	0.9	2.1	2.6	1.8	1.0	2.3	1.1	0.7	0.3
20	Wood and products of wood and cork	1.2	0.8	0.5	0.8	1.1	0.9	2.9	0.9	1.6	0.6	5.1	0.7	0.9	0.2
21	Pulp, paper and paper products	1.1	0.7	0.7	0.8	1.1	0.7	3.9	0.5	2.8	0.6	5.3	0.6	0.9	0.1
22	Printed matter and recorded media	1.0	0.6	0.7	0.5	1.0	0.4	3.9	1.9	2.8	2.6	5.3	2.3	0.9	0.3
23	Coke, refined petroleum products	2.1	10.2	1.4	2.8	3.4	3.2	5.1	1.2	1.6	1.7	4.9	1.8	1.7	1.8
24	Chemicals, chemical products	2.0	1.0	1.1	3.5	2.2	1.3	5.5	2.5	2.2	8.1	5.1	2.4	1.6	0.4
25	Rubber and plastic products	1.5	0.5	0.8	0.7	1.2	0.8	4.2	1.4	2.1	1.1	4.5	1.3	1.1	0.4
26	Other non-metallic mineral products	4.1	1.4	3.2	3.6	2.9	4.4	10.1	7.6	12.3	6.1	12.9	4.7	3.7	0.7
27	Basic metals	2.2	0.5	1.6	1.1	2.0	0.3	6.4	1.7	6.7	0.5	8.3	1.7	1.9	0.6
28	Fabricated metal products	2.6	1.0	1.6	1.9	1.9	1.1	6.2	3.2	6.7	2.3	7.8	3.0	1.9	0.9
29	Machinery and equipment n.e.c.	1.7	0.5	0.8	1.1	1.1	0.4	4.0	1.7	1.5	1.3	4.5	1.4	0.9	0.5
30	Office machinery and computers	0.9	0.2	0.8	0.4	1.0	0.3	3.3	0.7	0.0	1.4	3.8	1.1	0.9	0.3
31	Electrical machinery	1.3	0.2	0.8	1.3	1.0	0.2	3.3	1.2	1.8	1.0	4.2	1.3	0.9	0.3
32	Radio, television and comm. eq.	1.4	0.7	0.8	1.3	1.0	0.4	3.3	1.4	1.8	0.7	3.8	2.2	0.9	0.7
33	Medical and optical instruments	1.3	0.3	0.8	1.2	1.0	0.5	3.3	4.2	1.8	0.8	4.0	1.9	0.9	0.5
34	Motor vehicles, trailers	1.2	0.4	0.7	0.7	1.0	0.6	3.3	1.6	1.3	0.8	4.1	0.9	0.9	0.5
35	Other transport equipment	1.2	1.0	0.7	0.6	1.0	0.9	3.3	1.1	1.3	2.2	4.5	1.5	0.9	0.6
36	Furniture; other manufactured goods	1.3	0.2	0.6	8.7	1.0	0.4	3.3	1.6	2.1	1.6	2.9	0.9	1.0	0.4

Unit: percentage.

Non-EU countries: AUS: Australia; BRA: Brazil; CAN: Canada; CHN: China; IDN: Indonesia; IND: India; JPN: Japan; KOR: Korea; MEX: Mexico; RUS: Russia; TUR: Turkey; TWN: Taiwan; US: United States; ROW: Rest of the World.

Source: own elaboration.

Table 5.1. (Continuation) Tariffs on embodied emissions and tariffs on avoided emissions, by product and by country, 2009

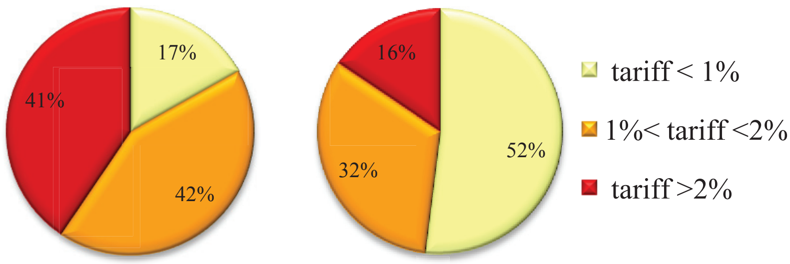
Product		KOR		MEX		RUS		TUR		TWN		US		ROW	
		Embodied emissions	Avoided emissions	Embodied emissions	Avoided emissions	Embodied emissions	Avoided emissions	Embodied emissions	Avoided emissions	Embodied emissions	Avoided emissions	Embodied emissions	Avoided emissions	Embodied emissions	Avoided emissions
15	Food products and beverages	1.6	0.5	1.1	0.8	2.2	1.7	1.2	0.7	1.5	1.2	1.4	0.9	1.3	1.0
16	Tobacco products	1.6	1.0	1.1	0.5	2.2	1.0	1.2	0.7	1.5	0.8	1.4	0.9	1.3	2.2
17	Textiles	2.1	1.3	1.6	1.2	2.6	2.0	1.1	1.4	2.7	1.5	1.5	0.8	1.7	2.0
18	Wearing apparel	2.1	1.4	1.6	0.6	2.6	0.8	1.1	0.9	2.7	1.7	1.4	0.7	1.6	1.3
19	Leather and leather products	1.6	0.7	1.1	0.8	2.7	1.4	0.9	1.2	1.6	1.4	1.4	1.1	1.5	1.1
20	Wood and products of wood and cork	1.9	0.3	1.4	0.3	3.3	1.3	2.2	0.6	1.5	0.4	1.8	0.6	1.5	0.9
21	Pulp, paper and paper products	2.1	0.5	1.4	0.7	3.1	0.7	1.3	0.8	2.6	0.3	1.3	0.5	1.5	0.7
22	Printed matter and recorded media	2.1	1.5	1.4	0.3	3.1	0.7	1.3	1.5	2.6	0.8	1.1	0.5	1.5	1.2
23	Coke, refined petroleum products	2.6	1.8	3.2	16.8	5.4	2.0	2.5	1.6	3.4	1.9	2.3	2.9	3.5	2.0
24	Chemicals, chemical products	2.7	2.2	1.7	2.3	9.5	3.3	1.4	2.6	3.8	1.6	1.9	0.8	3.4	1.5
25	Rubber and plastic products	2.1	0.8	1.6	0.6	4.5	0.7	1.9	1.0	2.3	0.9	1.4	0.4	8.0	1.0
26	Other non-metallic mineral products	7.4	1.6	5.2	3.3	12.8	7.8	7.4	4.9	12.3	4.2	4.9	1.3	7.1	6.4
27	Basic metals	4.1	0.9	2.3	1.2	10.3	1.3	2.7	2.0	4.2	1.3	1.9	0.9	2.8	0.7
28	Fabricated metal products	4.1	2.2	2.2	1.4	10.3	3.0	2.5	2.6	4.2	2.9	1.9	0.7	2.8	1.5
29	Machinery and equipment n.e.c.	1.9	1.1	1.3	0.7	4.5	1.2	1.5	1.4	1.8	1.1	1.0	0.5	1.9	0.6
30	Office machinery and computers	1.7	0.3	1.6	0.3	4.3	0.3	0.9	0.6	1.7	0.4	0.7	0.4	1.9	0.4
31	Electrical machinery	1.7	0.6	1.6	0.4	4.3	1.1	2.3	1.2	1.7	0.5	0.7	0.2	2.0	0.6
32	Radio, television and comm. eq.	1.7	0.5	1.6	0.4	4.3	0.8	1.2	1.0	1.7	0.7	0.7	0.6	1.9	1.1
33	Medical and optical instruments	1.7	1.3	1.6	0.8	4.3	0.2	1.2	3.1	1.7	1.6	0.7	0.4	2.2	0.5
34	Motor vehicles, trailers	1.8	0.9	1.1	0.6	3.4	1.0	1.2	0.7	1.7	0.9	1.1	0.5	1.5	0.8
35	Other transport equipment	1.8	0.2	1.1	1.6	3.4	3.1	1.3	0.8	1.7	0.9	1.1	0.8	1.5	0.4
36	Furniture; other manufactured goods	1.9	1.0	1.7	1.2	4.1	0.7	1.5	1.2	1.9	1.2	0.9	0.7	4.2	1.1

Unit: percentage.

Non-EU countries: AUS: Australia; BRA: Brazil; CAN: Canada; CHN: China; IDN: Indonesia; IND: India; JPN: Japan; KOR: Korea; MEX: Mexico; RUS: Russia; TUR: Turkey; TWN: Taiwan; US: United States; ROW: Rest of the World.

Source: own elaboration.

Figure 5.1. Percentage of products based on the tariff size



a. Embodied emissions **b. Avoided emissions**

Source: own elaboration.

5.4.2. Analysis at the product level

In this section, we analyze the results of the two systems: the so-called CBTA on embodied emissions and the CBTA on avoided emissions. For each system, we first measure the impact considering only the tax rates applied to different products and then taking also into account the trade volume of each product.

If we look at the tariffs obtained under a system based on embodied emissions, the products mostly affected would be "other non-metallic mineral products" (26).[73] For these products, the average rate would be higher than 2% in all the 14 non-EU countries, being particularly high (more than 10%) for products imported by China (10.1%), Indonesia (12.3%), India (12.9%), Russia (12.8%), and Taiwan (12.3%). These products are those whose emissions depend most on exporting countries' technologies: for all the countries considered, except for Canada, the emissions produced by each country are at least 90% of embodied emissions. In Indonesia and India these emissions are largely produced by the sector producing "other non-metallic mineral products." In China and Russia important proportions of emissions (32.1% and 32.8%) are embodied in the electricity needed to produce them. In Taiwan, one fifth of embodied emissions come instead from the extraction of raw material.

Other products that would especially be affected are "basic metals" (27) and "fabricated metal products" (28). For these products, the rates would be

[73] The number in parentheses after a product name refers to the product's number in Table 5.1.

high in particular for Russia (10.3% in both cases), India (8.2% and 7.4%), Indonesia (6.7% in both cases), and China (6.3% and 6.2%). China, India, Russia, and Taiwan would also have the highest rates for other energy-intensive products, such as “coke and refined petroleum products” (23) and “chemicals and chemical products” (24). For all these products, the analysis reveals a pattern of embodied emissions very similar to that described for “other non-metallic mineral products”: on average, roughly 80% of embodied emissions are generated in the exporting country. For “basic metals” (27) and “fabricated metal products” (28) produced in Russia and Indonesia, emissions are mainly due to the intensive use of energy of the producing sectors; for Chinese and Indian products within these classifications and for “coke and refined petroleum products” (23) or “chemical products” (24) from the countries listed previously, roughly half of the emissions embodied are due to the electricity needed to produce them. Some of these products would also have rates higher than 2% when imported from Australia, Canada, Korea, Mexico, Turkey, and the US, but in this case the contribution to emissions of the electricity sector would be much lower.

Finally, there are other products that would incur the highest taxes, but only when produced and imported by a few countries, in particular China, India, and Russia. For these three countries, many products would be taxed at rates higher than 3%: “wood and products of wood and cork” (20), “pulp, paper, and paper products” (21), “printed matter and recorded media” (22), “machinery and equipment” (29), “office machinery and computers” (30), “electrical machinery” (31), “radio, television, and communications equipment” (32), “medical and optical instruments” (33), “motor vehicles and trailers” (34), and “other transport equipment” (35). Once again, what these three countries have in common is that for all these products more than 90% of embodied emissions are generated in the exporting country; they also have in common a relevant role of the electricity sector in creating the emissions embodied in these products: for these products, on average, 47% of embodied emissions are due to the electricity sector.

So, to conclude, looking at tax rates at the product level, the main products affected would be the energy-intensive products, in particular when imported from China, Indonesia, India, Russia, Korea, and Taiwan. The many emissions embodied in energy-intensive products coming from these countries are clearly related to the technology needed to produce them, but also, especially for China, India, and Russia, to the highly polluting electricity sector.

Comparing the results obtained by simulating CBTA on avoided emissions to the previous results, two main characteristics are worth noting. First, the emissions avoided by the EU, or in other words the emissions that the EU would have produced if all products were made domestically, are on average very low. This suggests that a system based on avoided emissions in general implies tariffs lower than in a system based on embodied emissions: only for 15% of the products analyzed (42 out of 308) would a system based on avoided emissions imply rates higher than a system based on embodied emissions. Second, analyzing the 15% of goods that would be affected to a greater extent by a system based on avoided emissions, the products that would be taxed more are as follows: "tobacco products" (16) imported from Brazil, Indonesia, and Japan; "textiles" (17) from Brazil, Indonesia, and Turkey; "leather products" (19) from Austria, Canada, and Turkey; "chemical products" (24) imported from Brazil, Indonesia, and Turkey. This means that if these specific products were produced entirely in the EU, they would produce a higher amount of emissions. These results also show that CBTA based on avoided emissions would be higher than CBTA on embodied emissions mainly in three countries: Brazil, Indonesia, and Turkey.

Tax rates applied to different products provide a measure of the impact that CBTA would have. This effect would also depend on the total value of goods imported in the EU: a very high tax on basic metals imported from India might be insignificant if India were to trade just very few units with the EU. Taking into account trade volume as well reveals different information.[74] Figure 5.2 shows the 20 products of the 308 analyzed most affected by a CBTA system based on embodied emissions: these products would bear more than 60% of the total effect of the policy, represented by the width of each bubble, computed as the tax rates (shown on the horizontal axis) multiplied by the total value imported in the EU (shown on the vertical axis).[75] The main result that Figure 5.2 shows is that 14 out of

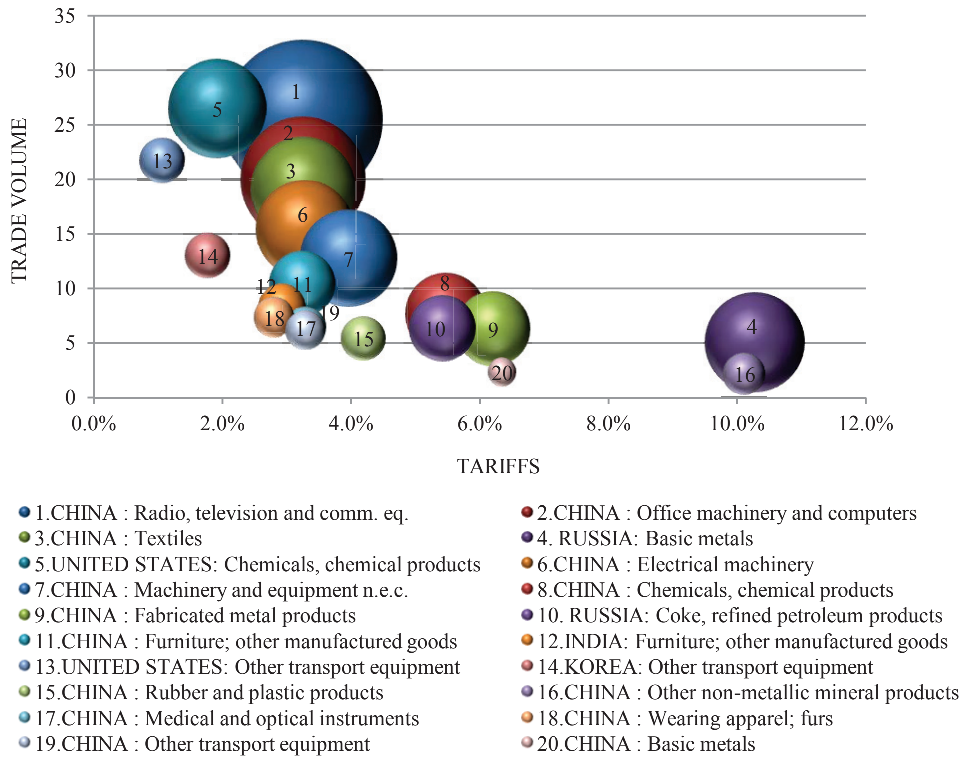
[74] Although the volume of goods imported would clearly change following the CBTA implementation, we propose a static quantification of the policy effect to take into account the actual size of trade flows.

[75] The region that would actually bear the most part of a CBTA system is the region "rest of the world", which would pay roughly 40% of the policy's cost. However, we do not

20 products imported from China alone would sustain roughly 30% of the policy's effect. The ranking of these products seems to be more closely related to the volume of trade than the severity of the rates imposed: the three most affected products, for example, would not be energy-intensive products, but "radio, television, and communications equipment" (32), "office machinery and computers" (30), and "textiles" (17).

Another interesting result is that two of the most affected products come from the US: "chemical products" (24) would be the fifth most affected product and "other transport equipment" (35) the thirteenth. Also, in this case it is due more to the volume of trade than to high tariffs (respectively 1.9% and 1.1%). Conversely, very high tax rates greater than the trade volume explain the cost the reform would imply for Russian products classified "coke and refined petroleum products" (23) and "basic metals" (27).

Figure 5.2. Products most affected, CBTA on embodied emissions

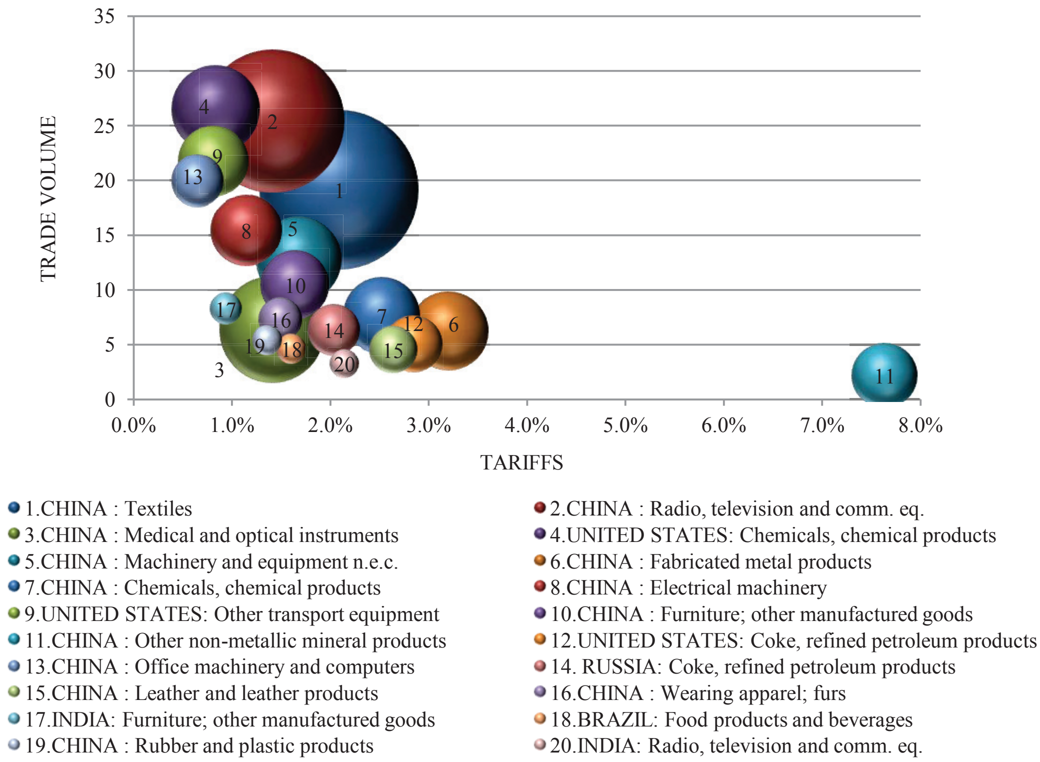


Unit: billions of euro.
Source: own elaboration.

analyze this region in detail because it aggregates several and different countries, and it would not be possible to provide a more detailed explanation for the results found.

Also, for the CBTA based on avoided emissions we show, in addition to the tariffs obtained, the effect of CBTA considering both the tax rates obtained and the volume of trade (Figure 5.3). Although the impact in absolute terms would be different, the ranking of the most affected products would change only partially. The reason is that the policy impact relies more on the volume of trade than on the severity of the tariffs imposed, as previously described. However, for some products, the two systems would imply a strongly different impact. This would be the case for "basic metals" (27) produced in Russia, which would be the fourth most affected category under a system based on embodied emissions, bearing 4.4% of the total policy impact, whereas it would bear 1.1% of the total impact under a system based on avoided emissions. Another example is Chinese "medical and optical instruments" (33), which would sustain only 1.6% of the total effect in the first scenario analyzed and 4.6% in the second.

Figure 5.3. Products most affected, CBTA on avoided emissions



Unit: billions of euro.
Source: own elaboration.

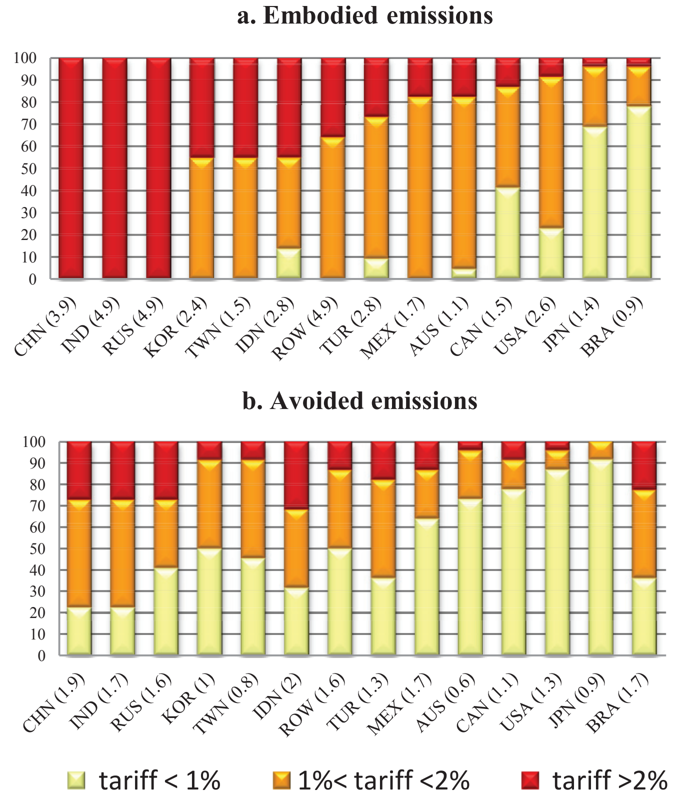
In the next section, we focus in greater depth on specific countries to show the overall effect of the two tax designs for each of them.

5.4.3. Analysis at the country level

Looking at the tax rates, differences between the two systems can also be found at the country level, with important differences between them (see Figure 5.4).

In Figure 5.4a, countries are ordered based on the spread of the CBTA over embodied emissions; in Figure 5.4b, the equivalent is shown for the CBTA on avoided emissions. For each country the label also shows, in parentheses, the average tariff applied. For three countries, China, India, and Russia, the differences between the two approaches would be very strong. Considering embodied emissions, 100% of their products would be charged at tariffs higher than 2%, and the average tariff would be, respectively, 3.9%, 4.9%, and 4.9%. Considering avoided emissions, only 27% of products would be greatly affected, with average tariffs of 1.9%, 1.7%, and 1.6%. Although in a less decisive way, for almost all the other countries, a CBTA system based on embodied emissions would also have a stronger impact than a CBTA based on avoided emissions in terms of both the level of the rates and their spread across products. The difference is less strong for Turkey, the US, Canada, Indonesia, Japan, and Australia. Brazil is the country that performs differently from the rest of the regions: in this case, a tariff system based on avoided emissions would be worse than a system based on embodied emissions. In particular, 16 products (73%) would be taxed more under a system designed on avoided emissions.

Figure 5.4. Percentage of products based on the tariff size, by country



Note: the averages in parenthesis are computed as simple averages without taking into account trade volumes.
Source: own elaboration.

Finally, also at the country level, it is interesting to show the effect of the two different CBTA systems in terms of the cost that they would imply. To do so, in Table 5.2 we express the impact of the policy for each non-EU country in three different ways.

First, we show weighted rates that represent the impact as a percentage of the total value of manufactured goods that any non-EU country exports to the EU (first two columns). So, for example, for Australia the total impact of a system based on embodied emissions would represent 1.6% of the value of manufactured goods that the country exports to the EU. As found before, under a system based on embodied emissions, the three most affected countries are Russia, India, and China. For these countries, the policy would imply an impact equal to, respectively, 7.2%, 4.0%, and 3.6% of the value of manufactured goods exported to the EU. The ranking changes under a system based on avoided emissions. In this case, Indonesia would be the most affected country, paying 1.9% of the value of manufactured goods exported to the EU. The result is different when we measure the impact as a percentage of the total trade value that each non-EU country exports to the EU (columns 3 and 4). The main change regards Russia. Raw materials being the most important trade flow with the EU, the cost of CBTA based on embodied (avoided) emissions would be only 1.8% (0.4%) of the total value imported from Russia. The last two columns show the share of the policy impact each country would bear. The result for the US is interesting: although a CBTA on embodied (avoided) emissions would represent only 1.3% (0.8%) of the value of manufactured goods imported from the US, and 0.6% (0.4%) of the total value imported, the US would be the third country in terms of share in the policy cost, bearing 7.5% (8.8%) of the total cost of the policy. This is due to the fact that the volume of trade between the US and the EU is very large.

Table 5.2. CBTA cost for each non-EU country

Non-EU Country	Percentage of the value of manufactures exported by any non-EU to the EU				Percentage of total trade value exported by any non-EU to the EU				Country's share of the policy cost			
	Embodied emissions		Avoided emissions		Embodied emissions		Avoided emissions		Embodied emissions		Avoided emissions	
Australia	1.6	[9] *	1.1	[8]	0.5	[13]	0.3	[12]	0.3	[14]	0.5	[14]
Brazil	0.8	[14]	1.7	[4]	0.3	[14]	0.7	[7]	0.6	[12]	2.4	[9]
Canada	1.5	[11]	0.9	[10]	0.5	[12]	0.3	[13]	0.7	[11]	0.9	[12]
China	3.6	[3]	1.7	[3]	2.9	[1]	1.4	[1]	29.6	[2]	29.1	[2]
Indonesia	2.1	[6]	1.9	[1]	1	[8]	0.9	[3]	0.8	[10]	1.5	[11]
India	4	[2]	1.4	[5]	2.2	[2]	0.8	[5]	5.3	[5]	3.9	[5]
Japan	1.1	[13]	0.6	[14]	0.9	[9]	0.5	[9]	2.4	[8]	2.6	[7]
Korea	2	[7]	0.7	[13]	1.6	[4]	0.6	[8]	3.5	[6]	2.4	[8]
Mexico	1.5	[10]	0.8	[11]	0.5	[11]	0.3	[14]	0.4	[13]	0.5	[13]
Russia	7.2	[1]	1.8	[2]	1.4	[5]	0.4	[11]	5.7	[4]	2.9	[6]
Turkey	1.7	[8]	1.4	[6]	1.3	[7]	1	[2]	3	[7]	4.9	[4]
Taiwan	2.3	[5]	1.1	[9]	1.8	[3]	0.9	[4]	1.6	[9]	1.6	[10]
US	1.3	[12]	0.8	[12]	0.6	[10]	0.4	[10]	7.5	[3]	8.8	[3]
RoW	2.6	[4]	1.3	[7]	1.4	[6]	0.7	[6]	38.5	[1]	38	[1]

Unit: percentage.
*: Countries ranking: [1] is the most affected country, [14] is the less affected.
RoW: rest of the world.
Source: own elaboration.

5.5. Conclusion

This Chapter has analyzed CBTA, a policy designed to avoid one of the drawbacks of emissions control instruments applied only to domestic products. It consists of tariffs on imports that level out different treatments for domestic and foreign products competing in the same market. In particular, we have analyzed the metric of CBTA, one of the topics of debate. We have assumed a 20 euro per ton of CO_2 tax applied in the EU and we have simulated two different possible CBTA systems. The first is based on emissions embodied in imports. The second is based on emissions the EU would produce to make the same product integrally within its borders, i.e., avoided emissions.

Looking at the main results, the two mechanisms would imply a different outcome in aggregate terms. A system designed to take account of embodied emissions would cost 2.5% of the total value of manufactured goods imported to the EU from non-EU countries (1.3% under a system based on avoided emissions). This result is in line with the findings of the existing literature. The difference between the two methods varies depending on the countries considered. For some countries (Australia, Indonesia, Japan, and the US) the rates computed under the two systems would be similar, whereas for other countries (such as China, India, or Russia) the difference would be really high.

On the one hand, a possible conclusion could be that a system based on avoided emissions is likely to be more acceptable due to its lower cost and due to the fact that products would not be treated differently depending on their origin. On the other hand, the analysis also makes it clear that a system based on avoided emissions would not target the real pollution content of the different goods. This conclusion is exemplified by the case of Brazil. Under a system based on avoided emissions, Brazilian products would be taxed more than under a system that takes into account the emissions actually contained in them. This is because, for this country, the average content of emissions is limited, especially thanks to an electricity production system with low carbon content. A system based on avoided emissions should take into account cases such as Brazil. Otherwise it would create a disincentive for emissions control, and it would go in the opposite direction of a policy, such as a carbon tax, which seeks to create incentives to reduce emissions.

The analysis also shows that China would largely be the main target country of an EU CBTA system under both metrics. This is caused by its highly polluting production system and electricity sector. It is also due to the volume of trade that exists between the EU and China. Moreover, given its crucial role in international trade relations, the Chinese production system is also responsible for an important share of emissions embodied in products, especially electronic ones, produced by other countries. Based on this result, the prospect of the EU implementing a CBTA system could serve as political leverage in reaching an international agreement after the Kyoto Protocol. Tariffs on imported goods have also been proposed in environmental policies as a measure to penalize countries that do not enter agreements on global problems such as climate change. Anyway, as this use of carbon tariffs does not necessarily imply a tax on carbon emissions, some authors even suggest that it would be easier to apply a general sanction tariff that is equal for all the goods imported from countries that do not enter the climate club (Nordhaus 2015).

In terms of analysis by product, two groups of goods would be most affected. On the one hand, there are energy-intensive products, such as coke, refined petroleum products, chemicals, chemical products, other non-metallic mineral products, basic metals, and fabricated metal products. Also, this result is in line with the existing literature. On the other hand, the analysis reveals that electronic products, such as radios, televisions, and office machineries, would also be highly exposed to CBTA due to the large volume traded with the EU. China, India, and Russia would be the countries most affected. When the volume of trade is considered, China assumes a predominant role. Also, the US would bear an important share of the CBTA cost under both designs, although the policy's cost would represent less than 2% of the manufactured goods the country exports to the EU. The results at the product level might suggest another element in the debate on the metric of CBTA. The impact of the policy would fall largely on two groups of products for different reasons. Energy-intensive products are among the most affected goods due to their carbon content. Non-energy intensive products, such as electronics, would also be affected strongly due to the large volume traded in the EU. Thus, an alternative solution to the higher impact of a CBTA based on embodied emissions could be to limit the tariff system only to certain products. This would also facilitate the practical implementation of CBTA. Indeed, it reduces the amount of information needed. A possible criterion for selecting products could consider those most exposed to the risk of leakage. This suggests the need for further analysis at the product level to determine which products could most suffer from carbon leakage.

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Appendices

Appendix 5.A. COMEXT database

Table 5.A.1. COMEXT products used in the analysis

Num.	COMEXT code, Product	Num.	COMEXT code, Product
1	1511 fresh and preserved meat (except poultry)	40	1753 nonwovens and articles made from nonwovens, except apparel
2	1512 fresh and preserved poultry meat	41	1754 other textiles n.e.c.
3	1513 meat and poultry meat products	42	1760 knitted or crocheted fabrics
4	1520 processed and preserved fish and fish products	43	1771 knitted and crocheted hosiery
5	1531 processed and preserved potatoes	44	1772 knitted and crocheted pullovers, cardigans articles
6	1532 fruit and vegetable juices	45	1810 leather clothes
7	1533 processed and preserved fruit and vegetables n.e.c	46	1821 work wear
8	1541 crude oil and fats	47	1822 outerwear
9	1542 refined oils and fats	48	1823 underwear
10	1543 margarine and similar edible fats	49	1824 other wearing apparel and accessories n.e.c.
11	1551 dairy products	50	1830 furs; articles of fur
12	1552 ice cream and other edible ice	51	1910 leather
13	1561 grain mill products	52	1920 luggage, handbags and the like; saddlery and harness
14	1562 starches and starch products	53	1930 footwear
15	1571 prepared animal feeds for farm animals	54	2010 wood, sawn, planed or impregnated
16	1572 prepared pet food	55	2020 veneer sheets; plywood, laminboard, particle board, fibre board and other panels and boards
17	1581 bread, fresh pastry goods and cakes	56	2030 builders' joinery and carpentry, of wood
18	1582 rusks and biscuits; preserved pastry goods and cakes	57	2040 wooden containers
19	1583 sugar	58	2051 other products of wood
20	1584 cocoa; chocolate and sugar confectionery	59	2052 articles of cork, straw and plaiting
21	1585 macaroni, noodles, couscous and similar farinaceous products	60	2111 pulp
22	1586 coffee and tea	61	2112 paper and paperboard
23	1587 condiments and seasonings	62	2121 corrugated paper and paperboard and containers of paper and paperboard
24	1588 homogenised food preparations and dietetic food	63	2122 household and toilet paper and paper products
25	1589 other food products	64	2123 paper stationery
26	1591 distilled alcoholic beverages	65	2124 wallpaper
27	1592 ethyl alcohol	66	2125 other articles of paper and paperboard n.e.c.
28	1593 wines	67	2211 books
29	1594 cider and other fruit wines	68	2212 newspapers, journals and periodicals, appearing at least four times a week
30	1595 other non-distilled fermented beverages	69	2213 newspapers, journals and periodicals, appearing less than four times a week
31	1596 beer made from malt	70	2214 sound recordings
32	1597 malt	71	2215 postcards, greeting cards, pictures and other printed matter
33	1598 mineral waters and soft drinks	72	2222 printing services n.e.c.
34	1600 tobacco products	73	2224 composition and plate-making services
35	1710 textile yarn and thread	74	2310 coke oven products
36	1720 textile fabrics	75	2320 refined petroleum products
37	1740 made-up textile articles, except apparel	76	2330 nuclear fuel
38	1751 carpets and rugs	77	2411 industrial gases
39	1752 cordage, rope, twine and netting	78	2412 dyes and pigments

Source: own elaboration from EUROSTAT data (EUROSTAT, 2015).

Table 5.A.1. (Continuation) COMEXT products used in the analysis

Num.	COMEXT code, Product	Num.	COMEXT code, Product
79	2413 other basic inorganic chemicals	124	2665 articles of fibre cement
80	2414 other basic organic chemicals	125	2666 other articles of plaster, concrete or cement
81	2415 fertilizers and nitrogen compounds	126	2670 monumental or building stone and articles thereof
82	2416 plastics in primary forms	127	2681 abrasive products
83	2417 synthetic rubber in primary forms	128	2682 other non-metallic mineral products n.e.c.
84	2420 pesticides and other agro-chemical products	129	2710 basic iron and steel and ferro-alloys (ecsc)
85	2430 paints, varnishes and similar coatings, printing ink and mastics	130	2721 tubes and tube fittings, of cast iron
86	2441 basic pharmaceutical products	131	2722 steel tubes and steel tube fittings
87	2442 pharmaceutical preparations	132	2731 cold drawn products
88	2451 glycerol, soap and detergents, cleaning	133	2732 cold-rolled of narrow strips
89	2452 perfumes and toilet preparations	134	2733 cold formed or folded products of iron, non-alloy steel or stainless steel
90	2461 explosives	135	2734 wire
91	2462 glues and gelatines	136	2735 ferro-alloys (non-ecsc) and other iron and steel n.e.c.
92	2463 essential oils	137	2741 precious metals
93	2464 photographic chemical material	138	2742 aluminium and aluminium products
94	2465 prepared unrecorded media	139	2743 lead, zinc and tin and products thereof
95	2466 other chemical products n.e.c.	140	2744 copper products
96	2470 man-made fibres	141	2745 other non-ferrous metal products
97	2511 rubber tyres and tubes	142	2811 metal structures and parts of structures
98	2512 retreaded pneumatic tyres, of rubber	143	2812 builders' carpentry and joinery of metal
99	2513 other rubber products	144	2821 tanks, reservoirs and containers of metal
100	2521 plastic plates, sheets, tubes and profiles	145	2822 central heating radiators and boilers
101	2522 packaging products of plastics	146	2830 steam generators (except central heating hot
102	2523 builder's ware of plastic	147	2861 cutlery
103	2524 other plastic products	148	2862 tools
104	2611 flat glass	149	2863 locks and hinges
105	2612 shaped and processed flat glass	150	2871 steel drums and similar containers
106	2613 hollow glass	151	2872 light metal containers
107	2614 glass fibres	152	2873 wire products
108	2615 other glass, processed, including technical glassware	153	2874 fasteners, screw machine products, chain and springs
109	2621 ceramic household and ornamental articles	154	2875 other fabricated metal products n.e.c.
110	2622 sanitary ceramic fixtures	155	2911 engines and turbines except aircraft, vehicle and cycle engines
111	2623 ceramic insulators and insulating fittings	156	2912 pumps and compressors
112	2624 technical ceramic wares	157	2913 taps and valves
113	2625 ceramic articles n.e.c.	158	2914 bearings, gears, gearing and driving elements
114	2626 refractory ceramic goods	159	2921 furnaces and furnace burners
115	2630 ceramic tiles and flags	160	2922 lifting and handling equipment
116	2640 bricks, tiles and construction products, in baked clay	161	2923 non-domestic cooling and ventilation equipment
117	2651 cement	162	2924 other general purpose machinery n.e.c.
118	2652 lime	163	2931 agricultural tractors
119	2653 plaster	164	2932 other agricultural and forestry machinery
120	2661 concrete products for construction purposes	165	2940 machine-tools
121	2662 plaster products for construction purposes	166	2941 portable hand held power tools
122	2663 ready-mixed concrete	167	2942 other metalworking machine tools
123	2664 mortars	168	2943 other machine tools n.e.c.

Source: own elaboration from EUROSTAT data (EUROSTAT, 2015).

Table 5.A.1. (Continuation) COMEXT products used in the analysis

Prod. Num.	COMEXT code, Product	Prod. Num.	COMEXT code, Product
169	2951 machinery for metallurgy	194	3410 motor vehicles
170	2952 machinery for mining, quarrying and construction	195	3420 bodies (coachwork) for motor vehicles; trailers and semi-trailers
171	2953 machinery for food, beverage and tobacco processing	195	3420 bodies (coachwork) for motor vehicles; trailers and semi-trailers
172	2954 machinery for textile, apparel and leather production	196	3430 parts and accessories for motor vehicles and their engines
173	2955 machinery for paper and paperboard production	197	3511 ships
174	2956 other special purpose machinery n.e.c.	198	3512 pleasure and sporting boats
175	2960 weapons and ammunition	199	3520 railway and tramway locomotives and rolling stock and parts thereof
176	2971 electric domestic appliances	200	3530 aircraft and spacecraft
177	2972 non-electric domestic appliances	201	3541 motorcycles
178	3001 office machinery and parts thereof	202	3542 bicycles
179	3002 computers and other information processing equipment	203	3543 invalid carriages
180	3110 electric motors, generators and transformers	204	3550 other transport equipment n.e.c.
181	3120 electricity distribution and control apparatus	205	3611 chairs and seats
182	3130 insulated wire and cable	206	3612 other office and shop furniture
183	3140 accumulators, primary cells and primary batteries	207	3613 kitchen furniture
184	3150 lighting equipment and electric lamps	208	3614 other furniture
185	3161 electrical equipment for engines and vehicles n.e.c.	209	3615 mattresses
186	3162 other electrical equipment n.e.c.	210	3621 coin and medals
187	3210 electronic valves and tubes and other electronic components	211	3622 jewellery and related articles n.e.c.
188	3220 television and radio transmitters, apparatus for line telephony and telegraphy	212	3630 musical instruments
189	3230 television and radio receivers, sound or video recording or reproducing apparatus and associated goods	213	3640 sports goods
190	3310 medical and surgical equipment and orthopaedic appliances	214	3650 games and toys
191	3320 instruments and appliances for measuring, checking, testing, navigating and other purposes	215	3661 imitation jewellery
192	3340 optical instruments and photographic equipment	216	3662 brooms and brushes
193	3350 watches and clocks	217	3663 other manufactured goods n.e.c.

Source: own elaboration from EUROSTAT data (EUROSTAT, 2015).

Appendix 5.B. Computing deflators

To compute tariffs based on avoided emissions, the analysis has to consider that usually the same product produced in different countries has different prices. We consider the EU as a single region. We compute the emissions that the EU would produce were it to produce the goods imported domestically, that is the avoided emissions. Once we obtain these, we need to apply a deflator for each product and each country to take into account international differences in prices. The deflator d_k^r of product k that the EU imports from country r is equal to the ratio between the domestic price of k in the EU and the price of the same good produced abroad and imported by the EU, $d_k^r = p_k^s / p_k^r$, s being the EU.

We obtain data on prices from the COMEXT database (Eurostat, 2015), which contains information on imports/exports to/from the EU in both monetary and physical terms. We obtain the prices of the imported product p_k^r by dividing the value of a product imported in Europe from a foreign country over its quantity. Regarding the domestic price of the EU product p_k^s, we compute the price of the products exported from EU, and we assume that the prices of products exported from EU are the same as the domestic price of EU products, because data in physical terms are available only for international trade flows.

By using data in monetary and physical terms from COMEXT, the prices obtained are those implicit in the COMEXT database. As the deflators are then applied to WIOD import data, we assume that prices in the two databases are the same.[76] There are two reasons for using data in monetary and physical terms from COMEXT. First, the database records imports in "cost, insurance, and freight" (CIF) prices and exports in "free on board" (FOB) prices. Also, as the WIOD uses CIF and FOB prices, assuming that prices are the same seems to be realistic. Second, using data in monetary terms from COMEXT has a further advantage as data are more disaggregated than in the WIOD. We use information for 217 COMEXT products to compute the deflators for the 22 WIOD products on which the analysis is focused.

[76] An alternative method would be to use data in monetary terms from the WIOD. This implies directly finding the prices of the WIOD database, but assuming that the quantities recorded in the two databases are the same.

Using aggregated data could cause a bias in the deflators computed, just because the relative weight of different sub-products belonging to the same aggregate category is different. Let us consider a simplified numerical example, in which the EU exports and imports two different manufactured food products, yogurt and wine, with a non-EU country. Let us also assume that while the European yogurt exported is twice as expensive as the imported yogurt (P_y^E=4, P_y^I=2), the price of a bottle of wine is the same (P_W^E = P_W^I =10). Finally, let us imagine that Europe exports 10 units of yogurt and 10 bottles of wine (Q_y^E=10, Q_w^E=10), and imports 50 units of yogurt and 10 bottles of wine (Q_y^I=50, Q_w^I=10). The values of exported and imported goods are thus: V_y^E=40, V_w^E=100, V_y^I=100, V_w^I=100. If data on the available values and quantities are disaggregated, by dividing the values over the quantities of yogurt and wine exported and imported we obtain the original prices, and the deflators obtained are equal to 2 for yogurt, 1 for wine. If data on values and quantities for the two products are aggregated (V^E=140, V^I=200, Q^E=20, Q^I=60), we obtain a price for the unique good exported (P^E=7) and a price for the unique product imported (P^I=3.3) biased by the relative weight of each product, resulting in a deflator equal to 2.1, which will be greater than the highest deflator obtained with disaggregated data.

Therefore, to compute a deflator for each WIOD product, we compute the prices of imports and exports with the highest disaggregation possible using COMEXT data, and we then aggregate in a single price for each WIOD category, weighting the prices for the quantities imported. In the previous numerical example, we would obtain an "adjusted" aggregated price of export $P^E_{adjusted}$ equal to 5, an "adjusted" aggregated price of import $P^I_{adjusted}$ equal to 3.3, and a deflator equal to 1.5.[77] Formally, the adjusted prices are computed as follows:

$$P_{adjusted}^E = \frac{P_y^E * Q_y^I + P_w^E * Q_w^I}{Q_y^I + Q_w^I} = 5$$

and

$$P_{adjusted}^I = \frac{P_y^I * Q_y^I + P_w^I * Q_w^I}{Q_y^I + Q_w^I} = 3.3$$

[77] An alternative way would be, inversely, to adjust the import price for the quantities exported. We choose the first alternative because the deflators obtained are then applied to adjust products imported by the EU.

Appendix 5.C. Deflators

Table 5.C.1. Deflators used in the analysis

Product		AUS	BRA	CAN	CHN	IDN	IND	JPN	KOR	MX	RUS	TUR	TWN	US	ROW
15	Food products and beverages	1.3	2.1	0.6	0.8	2.3	1.0	0.4	0.6	1.0	2.2	0.9	1.5	1.1	1.3
16	Tobacco products*	1.0	3.0	0.6	0.7	4.9	3.8	1.8	1.3	0.6	1.3	0.9	1.0	1.1	2.9
17	Textiles	1.0	1.7	2.1	3.0	3.7	2.4	0.7	1.8	1.7	2.9	2.1	2.2	1.2	2.9
18	Wearing apparel	1.0	1.6	0.6	2.2	1.5	2.1	0.3	2.0	0.9	1.2	1.4	2.5	1.0	1.9
19	Leather and leather products	3.5	1.8	1.9	5.3	2.1	2.2	0.5	1.3	1.6	2.9	2.4	2.8	2.1	2.1
20	Wood and products of wood and cork	1.1	1.0	1.2	1.2	0.8	1.0	0.3	0.4	0.4	1.8	0.8	0.5	0.8	1.3
21	Pulp, paper and paper products	1.0	1.1	0.9	0.7	0.8	0.8	0.2	0.6	1.0	1.0	1.1	0.4	0.7	0.9
22	Printed matter and recorded media	0.8	0.7	0.6	2.7	3.7	3.2	0.4	2.0	0.5	1.0	2.1	1.1	0.8	1.6
23	Coke, refined petroleum products	5.3	1.4	1.6	0.6	0.9	0.9	0.9	0.9	8.7	1.1	0.8	1.0	1.5	1.0
24	Chemicals, chemical products	0.9	3.2	1.2	2.3	7.4	2.2	0.4	2.0	2.1	3.0	2.4	1.5	0.8	1.4
25	Rubber and plastic products	0.7	1.0	1.1	1.9	1.5	1.8	0.6	1.1	0.9	0.9	1.4	1.2	0.6	1.4
26	Other non-metallic mineral products	0.5	1.3	1.5	2.7	2.1	1.6	0.3	0.5	1.1	2.7	1.7	1.5	0.4	2.2
27	Basic metals	0.4	0.9	0.2	1.4	0.4	1.4	0.5	0.7	1.0	1.1	1.6	1.1	0.7	0.6
28	Fabricated metal products	0.8	1.6	0.9	2.6	1.9	2.5	0.8	1.8	1.2	2.5	2.1	2.3	0.5	1.2
29	Machinery and equipment n.e.c.	0.9	1.9	0.7	2.9	2.3	2.4	0.9	1.9	1.1	2.0	2.5	2.0	0.8	1.0
30	Office machinery and computers	0.4	0.9	0.6	1.4	3.1	2.4	0.7	0.7	0.7	0.6	1.3	0.9	0.8	0.9
31	Electrical machinery	0.4	2.4	0.4	2.2	2.0	2.4	0.6	1.2	0.8	2.0	2.2	0.9	0.4	1.1
32	Radio, television and comm. eq.	1.4	2.7	0.7	2.9	1.5	4.5	1.5	1.1	0.8	1.7	2.2	1.4	1.3	2.2
33	Medical and optical instruments	0.6	2.5	1.0	8.4	1.6	3.7	1.0	2.6	1.6	0.4	6.2	3.1	0.8	1.0
34	Motor vehicles, trailers	0.7	1.2	1.0	2.7	1.4	1.6	0.9	1.5	1.0	1.7	1.2	1.5	0.9	1.3
35	Other transport equipment	1.7	1.0	1.4	1.8	3.6	2.5	1.1	0.3	2.6	5.1	1.4	1.5	1.3	0.7
36	Furniture; other manufactured goods	0.2	13.4	0.6	2.5	2.4	1.4	0.6	1.6	1.8	1.1	1.8	1.9	1.1	1.7

Non-EU countries: AUS: Australia; BRA: Brazil; CAN: Canada; CHN: China; IDN: Indonesia; IND: India; JPN: Japan; KOR: Korea; MEX: Mexico; RUS: Russia; TUR: Turkey; TWN: Taiwan; US: United States; ROW: Rest of the World.

*: The category "tobacco products" has been adjusted using additional more disaggregated data from the COMEXT database "EU Trade Since 1988 By SITC", following the nomenclature correspondence provided by Eurostat in the database RAMON available at http://ec.europa.eu/eurostat/ramon/relations/index.cfm?TargetUrl=LST_REL.

Source: own elaboration on EUROSTAT (2013) and WIOD (2013).

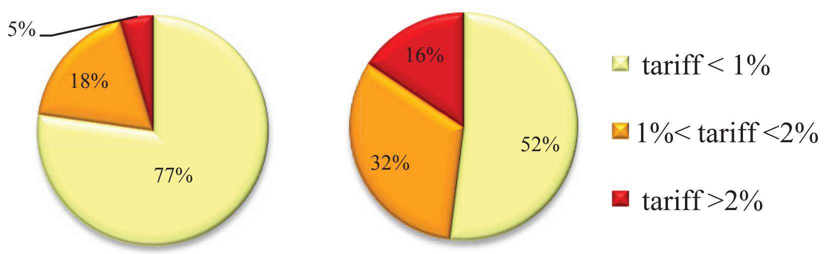
Appendix 5.D. Tariffs on avoided emissions: monetary terms

To compute tariffs based on the emissions of the abating region we consider avoided emissions applying the DTA. The use of this assumption implies considering together domestic and foreign inputs as they were entirely produced domestically by the abating region. Since input-output data are expressed in monetary terms, the use of the DTA makes it necessary to adjust for price differences across countries.

Figure 5.D shows the outcome obtained under a system based on avoided emissions. It shows the percentage of products that would be strongly taxed with rates higher than 2%, the percentage of products with rates between 1% and 2%, and the less affected products (with rates lower than 1%). In particular the Figure compares the results that we would have obtained without adjusting for international price difference (Figure 5.D.1a), with the results obtained adjusting for international price difference (Figure 5.D.1b).

The difference between the two graphs shows the bias that the use of the DTA can cause if international price differences are not taken into account. In this case the analysis would under-estimate the amount of emissions contained in products entirely produced in the abating region, then it would estimate lower tariffs. After deflating data, the percentage of products strongly affected would be higher compared with the percentage found without adjusting for price differences (16% instead of 5%). Also mildly affected products, as the strongly affected ones, would be proportionally more when adjusting for price differences (32% instead of 18%). This result suggests that, on average, products imported in the EU are cheaper than similar products produced domestically.

Figure 5.D.1. Percentage of products based on the tariff size



a. Avoided emissions (monetary) **b. Avoided emissions (adjusted for price differences)**

Source: own elaboration.

Additionally, Table 5.D.1 shows the tax rates obtained without deflating data or adjusting for price differences for any country and any product considered.

Table 5.D.1. CBTA by product for any non-EU country, corresponding to a 20€/tonCO_2 European carbon tax

		CBTA AE[(a)]	CBTA AE_d[(b)]													
			AUS	BRA	CAN	CHN	IDN	IND	JPN	KOR	MEX	RUS	TUR	TWN	US	ROW
15	Food products and beverages	0.8	1.0	1.6	0.5	0.6	1.8	0.8	0.3	0.5	0.8	1.7	0.7	1.2	0.9	1.0
16	Tobacco products	0.8	0.8	2.3	0.4	0.5	3.8	3.0	1.4	1.0	0.5	1.0	0.7	0.8	0.9	2.2
17	Textiles	0.7	0.7	1.2	1.5	2.1	2.5	1.6	0.5	1.3	1.2	2.0	1.4	1.5	0.8	2.0
18	Wearing apparel	0.7	0.7	1.0	0.4	1.5	1.0	1.4	0.2	1.4	0.6	0.8	0.9	1.7	0.7	1.3
19	Leather and leather products	0.5	1.8	0.9	0.9	2.6	1.0	1.1	0.3	0.7	0.8	1.4	1.2	1.4	1.1	1.1
20	Wood and products of wood	0.7	0.8	0.8	0.9	0.9	0.6	0.7	0.2	0.3	0.3	1.3	0.6	0.4	0.6	0.9
21	Pulp, paper and paper products	0.7	0.7	0.8	0.7	0.5	0.6	0.6	0.1	0.5	0.7	0.7	0.8	0.3	0.5	0.7
22	Printed matter and recorded media	0.7	0.6	0.5	0.4	1.9	2.6	2.3	0.3	1.5	0.3	0.7	1.5	0.8	0.5	1.2
23	Coke, refined petroleum products	1.9	10.2	2.8	3.2	1.2	1.7	1.8	1.8	1.8	16.8	2.0	1.6	1.9	2.9	2.0
24	Chemicals, chemical products	1.1	1.0	3.5	1.3	2.5	8.1	2.4	0.4	2.2	2.3	3.3	2.6	1.6	0.8	1.5
25	Rubber and plastic products	0.7	0.5	0.7	0.8	1.4	1.1	1.3	0.4	0.8	0.6	0.7	1.0	0.9	0.4	1.0
26	Other non-metallic min. products	2.9	1.4	3.6	4.4	7.6	6.1	4.7	0.7	1.6	3.3	7.8	4.9	4.2	1.3	6.4
27	Basic metals	1.2	0.5	1.1	0.3	1.7	0.5	1.7	0.6	0.9	1.2	1.3	2.0	1.3	0.9	0.7
28	Fabricated metal products	1.2	1.0	1.9	1.1	3.2	2.3	3.0	0.9	2.2	1.4	3.0	2.6	2.9	0.7	1.5
29	Machinery and equipment n.e.c.	0.6	0.5	1.1	0.4	1.7	1.3	1.4	0.5	1.1	0.7	1.2	1.4	1.1	0.5	0.6
30	Office machinery and computers	0.5	0.2	0.4	0.3	0.7	1.4	1.1	0.3	0.3	0.3	0.3	0.6	0.4	0.4	0.4
31	Electrical machinery	0.5	0.2	1.3	0.2	1.2	1.0	1.3	0.3	0.6	0.4	1.1	1.2	0.5	0.2	0.6
32	Radio, television and comm. eq.	0.5	0.7	1.3	0.4	1.4	0.7	2.2	0.7	0.5	0.4	0.8	1.0	0.7	0.6	1.1
33	Medical and optical instruments	0.5	0.3	1.2	0.5	4.2	0.8	1.9	0.5	1.3	0.8	0.2	3.1	1.6	0.4	0.5
34	Motor vehicles, trailers	0.6	0.4	0.7	0.6	1.6	0.8	0.9	0.5	0.9	0.6	1.0	0.7	0.9	0.5	0.8
35	Other transport equipment	0.6	1.0	0.6	0.9	1.1	2.2	1.5	0.6	0.2	1.6	3.1	0.8	0.9	0.8	0.4
36	Furniture; other manufactures	0.7	0.2	8.7	0.4	1.6	1.6	0.9	0.4	1.0	1.2	0.7	1.2	1.2	0.7	1.1

Unit: percentage.
Non-EU countries: AUS: Australia; BRA: Brazil; CAN: Canada; CHN: China; IDN: Indonesia; IND: India; JPN: Japan; KOR: Korea; MEX: Mexico; RUS: Russia; TUR: Turkey; TWN: Taiwan; US: United States; ROW: Rest of the World.
[(a)] Carbon border tax calculated on the emissions avoided by Europe through trade.
[(b)] Carbon border tax calculated on the emissions avoided by Europe through trade, adjusting for international prices differences.
Source: own elaboration.

Chapter 6

Summary and conclusion

6.1. Summary

The debate on atmospheric emissions, on the problem of global warming and on the possible policies to reduce atmospheric pollution continues to be extremely relevant today. The international community is trying to reach a new international agreement after the Kyoto Protocol. Lately some big regions have shown a greater involvement for future commitments. In November 2014 the United States (US) and China declared a negotiated deal to reduce their greenhouse gas (GHG) emissions (The Guardian, 2014).[78] As a further positive signal in dealing with the problem of atmospheric emissions, the private sector is also taking a step with respect to the issue. Six European big companies of the energy sector lately expressed support to emissions reduction policies (The New York Times, 2015). Being the US and China among the world main polluters, and being the private energy sector a key actor in the political debate on emissions reduction policies, these events provided an important boost for reaching a new international deal to reduce emissions in the next meeting of the United Nation Framework Convention on Climate Change (UNFCCC) to be held

[78] For the first time, China agreed to cup emissions by 2030. US committed a deep reduction of 26% to 28% below 2005 levels by 2025.

in Paris next December, 2015. The perspective of reaching a global agreement is very uncertain, though.

In this framework, the aim of this thesis was to provide new evidence on the evolution of atmospheric emissions and on some of the policy instruments to reduce them in order to enrich the debate on emissions evolution and emissions abatement policy. To achieve this purpose, we proposed four separate empirical analyses.

After a short introduction on the topic (Chapter 1), the first analysis proposed in Chapter 2 focused on the evolution of atmospheric emissions. Considering Italy as case study, the aim was to highlight how different economic factors have driven the evolution of Italian emissions before the economic crisis of 2008/2009; we analyzed the period 1995-2005. The driving factors considered were the evolution of technology, and changes in volume and structure of final demand. In particular we decomposed emissions evolutions to analyze how differently these determinants influenced two groups of gases: GHG emissions and acidification emissions. Moreover, in this first analysis we suggested a methodological proposal to take international trade into account since changes in trade flows could have played a role in the variation of Italian emissions. To this end, we decomposed the emissions that Italy generated, and also the emissions that Italy would have produced in the absence of trade. The general conclusion of the decomposition is in line with previous studies on the evolution of Italian emissions (Campanale and Femia, 2012; Cellura et al., 2012). The evolution of technology would have caused emissions to decrease but the volume of the final demand offset it. The main difference between the two groups of gases analyzed is that technological improvement is stronger, more durable and more effective for acidification emissions. This finding is in line with the environmental Kuznets curve hypothesis applied to local contaminants. The hypothesis does not hold for global contaminants such as carbon dioxide (CO_2). With respect to international trade, the methodology that we proposed led us to a conclusion different from the one previously found in literature. Contrary to the results suggested in Campanale and Femia (2012), trade does not seem to have strongly influenced the evolution of emissions in Italy in the period considered.

While the first study, more methodological, examined how different determinants influenced the evolution of atmospheric emissions, the remaining analyses focused on policies to reduce emissions related in particular to environmental taxation.

Chapter 3 focused on a specific policy to reduce emissions, the European energy tax. In 2011 the European Commission proposed a reform of the tax that was not approved by the Parliament. Our analysis showed the possible effects of the reform on the level of prices in 27 of the countries belonging to the European Union (EU). We found that the impact of the reform would be pretty much limited in its extent as in its intensity. The reform would entail also a different effect depending on the country and the sector analyzed. More specifically, the Eastern European countries would support the higher cost. The most affected sectors were mining, chemicals, and inland transport. These findings show the difficulty of implementing emissions reduction policies even when the expected impact is relatively low. Other reasons besides the economic effect of the reform seem to have guided the political choice. Among these reasons, one is that fiscal reforms in the EU require unanimity, but some countries are resistant to give competences to the UE in this field. We also considered that in the context of an enduring economic crisis environmental issues have become less priority. Last but not least the strong opposition of some pressure groups that the reform would hit mattered too.

In Chapter 4 we complemented the analysis proposed in Chapter 3. For one specific country, Italy, we obtained a database on the use of energy products more disaggregated than the one used in the previous analysis. We used this database to check if the results previously found are sensible to data disaggregation and to the model used. Indeed, having obtained disaggregated data only for Italy, in this Chapter we simplified the theoretical framework using a single-region model. Comparing the two applications, the results found are qualitatively very similar. In both cases most of the sectors would be slightly affected. We conclude that the approximations applied in the two analyses do not alter the results strongly. Although a single-region model is less realistic than a multi-region model, this result suggests that it can still be a useful tool when enabling the use of data available only for one region. Anyway, we cannot generalize this conclusion that might be case-specific. Each application proposed implies a simplification. In the application with a multi-regional model data are less disaggregated. In the analysis that applies a single-region model the description of the technology is less realistic. So in the comparison we cannot recognize what role any of these approximations has in influencing the results. The use of a single-region model might be complemented with other information to check its reliability.

Finally, Chapter 5 analyzed carbon-motivated border tax adjustment (CBTA). CBTA are tariffs applied to imports to avoid possible negative effects of emissions abatement policies such as environmental taxes when they are implemented only locally. The analysis focused in particular on CBTA metric. We computed and compared two possible CBTA systems that the EU could implement to compensate a hypothetical carbon tax applied to domestic products. In one system tariffs are computed on the basis of the emissions generated abroad to produce the goods then imported by the EU (embodied emissions). In the second system tariffs are based on the emissions that the EU would have generated to produce the same products domestically (avoided emissions). In line with the existing literature, we found that the two metrics imply very different results. The impact of a system based on avoided emissions would be half the impact of a system based on embodied emissions. Considering its low impact, it could be politically more acceptable. Taking trade volume into account, China alone would bear the 30% of the policy impact. Although it would be the most affected country under both metrics, the impact would be much lower under a system based on avoided emissions. On the contrary we found some exemptions to the general rule: for Brazil products would be in general taxed more under a system based on avoided emissions. These results suggest that, although a system based on avoided emissions could be more acceptable for the most part of exporters to the EU and for the World Trade Organization, it is also clear that it does not contain rewards for low emissions or penalties for high contamination.

6.2. Conclusion

Each of the analyses developed in this work has provided new evidence on some of the issues related with air emissions and emissions abatement policies. In each Chapter we have highlighted some conclusions related to the specific analysis proposed. In addition to this, the work leads to two conclusions of a more general nature.

The first conclusion regards the methodology used. In all the analyses we have taken advantage of the framework provided by the input-output approach. As it is well known, the input-output analysis provides a theoretical framework for analyzing relationships between the production and consumption sectors of an economy (Leontief, 1936). The capability of this approach to examine the interactions among different parts of the economic system opens a way to study not only monetary flows and employment but also the effects of production and/or consumption on the environment. In particular, the different analyses proposed in this thesis used two different approaches depending on their scope: the single-region approach and the multi-region approach. Chapter 2 and 4 applied a single-region model, Chapter 3 a multi-region approach, and Chapter 5 employed both models. Single-region models were more frequently applied before multi-region databases were made available. Lately more comprehensive multi-region frameworks have been used more, offering more reliable information about the technological processes used to produce goods and services domestically and abroad. On the contrary, a single-region framework assumes that products imported into a region have been produced using the same technology available in the region analyzed (domestic technology assumption). The assumption necessary to use the single-region approach is therefore less realistic and less accurate than multi-region approaches. In any case, the analyses show that there is still room for its use. It can be useful when it enables the use of data available only for one or few regions, as in Chapter 4, and when the analysis focuses on avoided emissions, as in Chapters 2 and 5. In fact, in Chapter 2 its use permits to compute avoided emissions to verify how international trade influenced the evolution of emissions in Italy. Also in Chapter 5 we use it to compute avoided emissions to simulate a CBTA system based on emissions the EU would have generated to domestically produce the goods imported from abroad.

A second general conclusion regards the last three chapters focused on emissions abatement policies, in particular on carbon tax as an environmental policy. From a theoretical perspective, carbon taxes, including the cost for carbon pollution in prices, create a price signal necessary to induce changes in consumption and in energy investment, and to reduce emissions that are causing global warming. Moreover, they are one of the mechanisms for emissions control considered cost-efficient. In fact, they give polluters an incentive to reduce their pollution, and they ensure that those who can do it most cheaply undertake pollution reductions. However, the analyses in this thesis reveal some of the difficulties to implement this type of policy in practice. Chapters 3 and Chapter 4 show that in the case of the EU, even a proposal that would have a relatively modest impact on prices was not implemented. It is true that the EU is applying another economic tool to reduce emissions, the European Emissions Trading System (ETS), but in the last years the ETS has not given a price signal sufficiently clear to induce a change in consumption and investment, and a carbon tax could complement it. In addition, a carbon tax applied at the EU level would not solve the problem of policies applied unilaterally by only one or a few regions. The analysis in Chapter 5 shows that a compensation for a fiscal policy not applied on a global scale can be complex. In the specific case analyzed, a CBTA designed to compensate for a carbon tax applied at the EU level would ultimately be a policy affecting significantly only few countries, especially China and some less developed countries. Moreover, in this case the nature of this environmental policy tool and its ability to generate incentives for changes in consumption and investment might be limited by the need for consistency with the rules of the World Trade Organization. The work proposed in this thesis and the results found corroborate the idea that policies for reducing emissions are both necessary and difficult to implement. For this it leads to the conclusion that it is necessary to continue in this line of research, in order to provide more analytical tools and more empirical evidence to the political debate.

6.3. Future research

The studies that constitute this thesis are a starting point for future lines of research.

There are some possible short-term extensions that would permit to improve the analyses proposed. To complete Chapter 2 in view of a possible publication, it would be important to check if the results found still hold in more recent years. Since an update version of data used has been lately released, it would be possible to show if the trends found still persist. Moreover, to verify the method proposed, the analysis could be complemented comparing the results found for Italy with the results we would obtain considering another country that could have suffered of carbon leakage more. As a further extension of the analysis, it could also be useful to check the robustness of the results found by applying different methodologies. An alternative approach might be a multi-region framework. This approach would imply a different perspective, analyzing the emissions actually generated in foreign countries to produce the goods imported by Italy, and it would also permit a comparative analysis considering different countries and regions.

Regarding Chapters 3 and 4, it would be interesting to enlarge the analysis in order to show more broad effects that the reform analyzed would have implied. General equilibrium models or econometric input-output models offer a useful framework to this scope. They would permit to take into account how the variation in prices obtained in Chapters 3 and 4 would influence consumers and producers choices. They would also permit to consider different options to use the revenues generated through the increased taxation.

Regarding Chapter 5, we will try to refine the work done so far in order to publish it. Moreover, similarly to Chapters 3 and 4, as a possible extension we would like to use the results obtained in a broader framework, to provide a more detailed analysis about the effects of the implementation of the policy analyzed on trade flows, considering for example the elasticity of trade flows with respect to prices. This would also permit to compare our analysis based on World Input Output database with the other papers that offer a similar analysis based on data from the Global Trade Analysis Project (Mattoo et al., 2009; Böhringer et al., 2012; Elliott et al., 2013). For such a comparison it would be interesting also to provide and analyze different policy scenarios. We could consider for example how results change if not only the EU but also other regions apply a domestic carbon tax.

Other possible extensions of this thesis are in a more long-term perspective. In particular, considering the last three chapters focused on emissions reduction policies, future research could be developed taking into account the redistribution effect of the instruments analyzed. In fact, the environmental policies' impact might be distributed unequally across society. The knowledge of the implication of any policy in terms of income distribution is relevant information for the political debate on them. There are different possible approaches already suggested in literature. Following

Wier et al. (2005) and Kerkhof et al. (2008), the income distribution effect of an environmental policy can be studied combining input-output analysis with the information contained in national consumer surveys. Alternatively it can be combined with econometric analyses as proposed by Brännlund and Nordström (2004), Labandeira et al. (2009), or Mongelli et al. (2010). Considering for example the reform of the energy tax directive (ETD) analyzed in Chapters 3 and 4, one of the concerns expressed in the European Parliament by the representatives of some countries who vetoed the proposal was not to apply additional tax burdens on citizens already struggling due to the current economic crisis. For the ETD reform, as well as for a hypothetical CBTA system, it would be important to understand also the effect in terms of possible redistribution within each country.

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Annexes

Annex A. ISTAT and WIOD databases description

The main databases used belong to sets of input-output tables and environmental satellite accounts.

The input-output framework offers mainly two kinds of information, supply and use tables (SUT), and input-output tables (IOT). SUT collect information in "product-industry" format. Supply tables represent the value of goods and services supplied by domestic production activities and by means of import, while use tables give information on the value of goods and services purchased by economic sectors and by final demand and information on the value added. These tables record primary as well as "non-characteristic" or secondary production, taking into account the fact that an industry usually produces more than one commodity. IOT transform the information content in SUT, and they make the use of theoretical input-output models possible. Chapter 2 and 4 are based on the national input-output tables offered by the Italian National Statistical Institute (ISTAT) (ISTAT 2010a; 2011); Chapter 3 and 5 are based on the world input-output tables provided by the World Input Output Database (WIOD) project (WIOD, 2013).

The satellite accounts register the flows between economy and environment. Both ISTAT and WIOD make available environmental accounts suitable with the information contained in input-output tables (ISTAT 2010b, and WIOD 2012).

The two following sections (A.1 and A.2) describe, respectively, ISTAT and WIOD databases used. Sub-section A.3 proposes a simplified example to compare how data are recorded in a multi-regional set such as in WIOD, or in a single-region set such as in ISTAT data.

A.1. ISTAT database

In the ISTAT edition of input-output tables used in Chapter 2 and 4 (ISTAT 2010a; 2011), yearly data are available for the period 1995-2006 and 1995-2008 respectively. Supply and use tables are presented at current prices as well as at prices of former years, and they are available in two different the disaggregation levels: 59 industries and 59 products, or 30 industries and 30 products (see Table A.1 for a list of industries, and Table A.2. for a list of products available). The used classification is the “National Classification of Economic Activities” (NACE) Rev 1.1 (Eurostat 2002), for industries, and “Classification of Product by Activities” (CPA) (Eurostat 2008a), for products. Input-output tables at basic current prices are available for the years 1995, 2000, 2005. There are two different input-output tables, both with dimension 59x59: the table “product-by-product” generated under the industry technology assumption, and the table “industry-by-industry” based on the assumption of fixed product sales structure. Using the industry technology assumption the secondary production is allocated assuming that each industry has its own specific technical process, used to produce any product. This assumption best applies to cases where several products are produced in a single production process (as in the cases of by-production or joint production). The assumption of fixed product sales structure states that each product has its own specific sales structure, irrespective of the industry where it is produced. Finally, the set of input-output tables also includes the use table and the input-output table for import with the same dimension as the total input-output tables (for a complete explanation of different methods and assumption for the construction of input-output tables from SUT, see Miller and Blair (2009), cap. 5, and Eurostat (2008b), cap. 11).

Regarding the satellite accounts, the Italian National Accounting Matrix including Environmental Accounts (NAMEA) combines an economic module that offers information on economic aggregates obtained from national accounts with data on atmospheric emissions. The structure of NAMEA tables is the same as the SUT: economic and environmental data are assigned to different industries by considering also secondary productions. The Italian NAMEA tables used are tables available for the period 1990-2006 (ISTAT, 2010b). The number of industries available for the years 1995-2006 is 51. Nineteen atmospheric pollutants are reported in physical units (see table A.3 for a list of air emissions). Data on emissions are split between emissions caused by economic activities and emissions caused directly by household (mainly due to heating and transport).

Table A.1. ISTAT sectors

Number	WIOD code	Sector
1	01	Agriculture, hunting and forestry
2	02	Forestry and related services
3	05	Fishing
4	10	Mining of coal, extraction of peat
5	11	Extraction of crude oil and natural gas and related services
6	12	Mining of uranium and thorium
7	13	Mining of metal ores
8	14	Other mining and quarrying
9	15	Manufacture of food products, beverages and tobacco
10	16	Tobacco Industry
11	17	Manufacture of textiles
12	18	Manufacture of wearing apparel; dressing and dyeing of fur
13	19	Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear
14	20	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
15	21	Manufacture of pulp, paper and paper products
16	22	Publishing, printing and reproduction of recorded media
17	23	Manufacture of coke, refined petroleum products and nuclear fuel
18	24	Manufacture of chemicals, chemical products and man-made fibres
19	25	Manufacture of rubber and plastic products
20	26	Manufacture of other non-metallic mineral products
21	27	Manufacture of basic metals
22	28	Manufacture of fabricated metal products, except machinery and equipment
23	29	Manufacture of machinery and equipment n.e.c.
24	30	Manufacture of office machinery and computers
25	31	Manufacture of electrical machinery and apparatus n.e.c.
26	32	Manufacture of radio, television and communication equipment and apparatus
27	33	Manufacture of medical, precision and optical instruments, watches and clocks
28	34	Manufacture of motor vehicles, trailers and semi-trailers
29	35	Manufacture of other transport equipment
30	36	Manufacture of furniture; manufacturing n.e.c., recycling
31	37	Recovery and recycling
32	40	Electricity and gas
33	41	Collection, purification and distribution of water
34	45	Construction
35	50	Sale, maintenance and repair of motor vehicles and motorcycles
36	51	Wholesale, motor vehicles and motorcycles
37	52	Retail trade, motor vehicles and motorcycles
38	55	Hotels and restaurants
39	60	Land transport; transport via pipelines
40	61	Water transport
41	62	Air transport
42	63	Auxiliary transport activities, travel agencies
43	64	Post and telecommunications
44	65	Financial intermediation, except insurance and pension funding
45	66	Insurance and pension funding, except compulsory social security
46	67	Activities auxiliary to monetary and financial
47	70	Activities of real estate services
48	71	Rental of machinery

Source: own elaboration from ISTAT data (ISTAT, 2010a).

Table A.1. (Continuation) ISTAT sectors

Sector number	WIOD code	Sector
49	72	Computer and related activities
50	73	Research and development (R & D)
51	74	Other professional entrepreneurial
52	75	Larger public administration and defense; compulsory social security
53	80	Education
54	85	Health and social work
55	90	Sewage and refuse disposal, sanitation and similar activities, Activities of membership organizations n.e.c., Other service activities
56	91	Interest groups
57	92	Recreational, cultural and sporting activities
58	93	Other services
59	95	Domestic services

Source: own elaboration from ISTAT data (ISTAT, 2010a).

Table A.2. ISTAT products

Product number	ISTAT code	Product
1	01	Products of agriculture, hunting and related services
2	02	Forestry products and related services
3	05	Fish and other seafood; ancillary services fisheries
4	10	Coal
5	11	Oil and natural gas; ancillary services to the extraction of oil and gas
6	12	Uranium and thorium
7	13	Mining of metal ores
8	14	Other products of the extractive industries
9	15	Food & Beverage
10	16	Tobacco Industry
11	17	Textiles
12	18	Clothing and fur
13	19	Leather and leather products
14	20	Wood and products of wood and cork (except furniture)
15	21	Paper and paper products
16	22	Publishing and Printing
17	23	Coke and refined petroleum products
18	24	Chemical products and man-made fibers
19	25	Rubber and plastic products
20	26	Other non-metallic minerals
21	27	Metals and alloys
22	28	Metal products, except machinery and equipment
23	29	Mechanical products
24	30	Office machinery and computers
25	31	Machinery and equipment n.a.c.
26	32	Radio television
27	33	Medical, precision, optical instruments and watches
28	34	Motor vehicles and trailers
29	35	Other means of transport
30	36	Furniture and other manufactured goods

Source: own elaboration from ISTAT data (ISTAT, 2010a).

Table A.2. (Continuation) ISTAT products

Product number	ISTAT code	Product
31	37	Material recovery
32	40	Electricity, gas and steam
33	41	Collection and distribution of water
34	45	Buildings
35	50	Trade, maintenance and repair of motor vehicles and motorcycles.
36	51	Wholesale trade, except motor vehicles and motorcycles
37	52	Retail trade, excluding motor vehicles and motorcycles
38	55	Hotels and restaurants
39	60	Ground transportation
40	61	Maritime transport
41	62	Air transport
42	63	Transport auxiliary; travel agencies
43	64	Post and telecommunications
44	65	Financial intermediation, except insurance and pension funding
45	66	Insurance and pension funding, except compulsory social security
46	67	Auxiliary services Financial intermediation
47	70	Real estate activities
48	71	Rental of machinery
49	72	Computer and related services
50	73	Research and development (R & D)
51	74	Professional activities
52	75	Public administration and defense; compulsory social security
53	80	Education
54	85	Health and Social Services
55	90	Waste disposal, sanitation and similar services
56	91	Membership organizations
57	92	Recreational, cultural and sporting activities
58	93	Services
59	95	Domestic services

Source: own elaboration from ISTAT data (ISTAT, 2010a).

Table A.3. ISTAT NAMEA data

NAMEA group number	NAMEA group, pollutant
1	In tons: CO_2 (carbon dioxide), N_2O (nitrous oxide), CH_4 (methane), NO_x (nitrogen oxides), SO_x (sulphur oxides), NH_3 (ammonia), COVNM (composed organic volatile not methane), CO (carbon monoxide), particulate PM10, particulate PM25.
2	In kilograms: As (arsenic), Cd (cadmium), Cr (chrome), Cu (copper), Hg (mercury), Ni (nickel), Pb (lead), If (selenium), and Zn (zinc)

Source: own elaboration from ISTAT data (ISTAT, 2010b).

A.2. WIOD database

The main database used in Chapters 3 and 5 is the one made available by the WIOD project since April 2012, updated in November 2013 (WIOD, 2013). The WIOD database consists of four main time series: world input-output tables and international supply and use tables (WIOT-ISUT); national input-output tables and national supply and use tables (NIOT-NSUT); socio-economic accounts (SEA); environmental accounts (EA). All data are at annual basis, available for the period 1995-2011, except for EA, available for the years 1995-2009. They are disaggregated by country, economic sector, and product (see Table A.4 for a complete list of countries, Table A.5 for a list of the sectors, and Table A.6 for a list of the products available). The used classification is the same as for ISTAT data: the NACE Rev 1.1 for sectors (Eurostat, 2002), and CPA for products (Eurostat, 2008b). WIOT-ISUT and NIOT-NSUT are expressed in monetary terms, SEA in monetary, units, and prices, while EA in physical terms.

The full set of the WIOT-ISUT tables contains international supply and use tables at current and previous year prices, with the use table split into domestic and import by country (35 industries by 59 products), world input-output tables at current and previous year prices (35 industries by 35 industries), and interregional input-output tables of the same dimension for 6 regions: EU27, other EU, NAFTA (Canada, Mexico, US), China, East Asia (Japan, Korea, Taiwan), BRIIAT (Brazil, Russia, India, Indonesia, Australia, Turkey), and the rest of the world.

NIOT-NSUT offers national supply and use tables at current and previous year prices, and national input-output tables at current prices. National tables have the same scope as international tables. Moreover, both national and international input-output tables are industry-by-industry, estimated under the assumption of fixed product sales structure.

SEA contains information about industry output, value added, capital stock, investment, wages and employment by skill type, disaggregated in 35 industries.

Finally, WIOD EA record data about use of energy, air emissions, use of mineral and fossil resources, land use, and water use. This satellite accounts have the same sector breakdown and geographical coverage as the WIOT-ISUT series. Energy data are gross energy use, and emission relevant energy use. Data include energy flows in physical terms (terajoules, TJ), related to 26 energy products (see Table A.7). Emission relevant energy use is derived from the gross energy use but excluding the non-energy use and the inputs for transformation into energy products. Air emissions accounts include CO_2 emissions (in 1000 tons) desegregated by sector and energy commodity, and non-CO_2 emissions (in tons) by sector (see Table A.8 for a list of air emissions available). CO_2 emissions include both energy-related air emissions, that result directly from the use of energy through fuel combustion, and non-energy related air emissions, that are not directly related to the combustion process, such as industrial process including mineral, chemical and other production sectors, agriculture including manure, agriculture soils and field burning and waste. Material extraction accounts include used materials (in 1000 tons) and unused extraction (in 1000 tons) (see Table A.9 for a list of materials available). Use of land (in 1000 hectares) accounts for land used by agriculture and forest sector by type of land (see Table A.10), while water use (in 1000 cubic meters) is by sector and type of water (see Table A.11).

Table A.4. WIOD countries

European Countries		**Non-European Countries**
Austria	Latvia	Australia
Belgium	Lithuania	Brazil
Bulgaria	Luxembourg	Canada
Cyprus	Malta	China
Czech Republic	Netherland	Indonesia
Denmark	Poland	India
Estonia	Portugal	Japan
Finland	Romania	Korea
France	Slovak Republic	Mexico
Germany	Slovenia	Russia
Greece	Spain	Turkey
Hungary	Sweden	Taiwan
Ireland	UK	United States
Italy		Rest of the World

Source: own elaboration from WIOD data (WIOD, 2013).

Table A.5. WIOD sectors

Sector number	**WIOD code**	**Sector**
1	AtB	Agriculture, hunting, forestry and fishing
2	C	Mining and quarrying
3	15t16	Food, beverages and tobacco
4	17t18	Textiles and textile products
5	19	Leather, leather and footwear
6	20	Wood and products of wood and cork
7	21t22	Pulp, paper, paper , printing and publishing
8	23	Coke, refined petroleum and nuclear fuel
9	24	Chemicals and chemical products
10	25	Rubber and plastics
11	26	Other non-metallic mineral
12	27t28	Basic metals and fabricated metal
13	29	Machinery, nec
14	30t33	Electrical and optical equipment
15	34t35	Transport equipment
16	36t37	Manufacturing, nec; recycling
17	E	Electricity, gas and water supply
18	F	Construction
19	50	Sale, maintenance and repair of motor vehicles and motorcycles; retail sale of fuel
20	51	Wholesale trade and commission trade, except of motor vehicles and motorcycles
21	52	Retail trade, except of motor vehicles and motorcycles; repair of household goods
22	H	Hotels and restaurants
23	60	Inland transport
24	61	Water transport
25	62	Air transport
26	63	Other supporting and auxiliary transport activities; activities of travel agencies
27	64	Post and telecommunications
28	J	Financial intermediation
29	70	Real estate activities
30	71t74	Renting of m&eq and other business activities
31	L	Public admin and defence; compulsory social security
32	M	Education
33	N	Health and social work
34	O	Other community, social and personal services
35	P	Private households with employed persons

Source: own elaboration from WIOD data (WIOD, 2013).

Table A.6. WIOD products

Number	WIOD code	Product
1	1	Products of agriculture, hunting and related services
2	2	Products of forestry, logging and related services
3	5	Fish and other fishing products; services incidental of fishing
4	10	Coal and lignite
5	11	Crude petroleum and natural gas
6	12	Uranium and thorium ores
7	13	Metal ores
8	14	Other mining and quarrying products
9	15	Food products and beverages
10	16	Tobacco products
11	17	Textiles
12	18	Wearing apparel
13	19	Leather and leather products
14	20	Wood and products of wood and cork (except furniture)
15	21	Pulp, paper and paper products
16	22	Printed matter and recorded media
17	23	Coke, refined petroleum products and nuclear fuel
18	24	Chemicals, chemical products and man-made fibres
19	25	Rubber and plastic products
20	26	Other non-metallic mineral products
21	27	Basic metals
22	28	Fabricated metal products, except machinery and equipment
23	29	Machinery and equipment n.e.c.
24	30	Office machinery and computers
25	31	Electrical machinery and apparatus n.e.c.
26	32	Radio, television and communication equipment and apparatus
27	33	Medical, precision and optical instruments, watches and clocks
28	34	Motor vehicles, trailers and semi-trailers
29	35	Other transport equipment
30	36	Furniture
31	37	Recovered secondary raw materials
32	40	Electrical energy, gas, steam and hot water
33	41	Collected and purified water, distribution services of water
34	45	Construction work
35	50	Trade, maintenance and repair services of motor vehicles and motorcycles
36	51	Wholesale trade and commission trade services
37	52	Retail trade services, except of motor vehicles and motorcycles
38	55	Hotel and restaurant services
39	60	Land transport and transport via pipeline services
40	61	Water transport services
41	62	Air transport services
42	63	Supporting and auxiliary transport services
43	64	Post and telecommunication services
44	65	Financial intermediation services, except insurance and pension funding services
45	66	Insurance and pension funding services, except compulsory social security services
46	67	Services auxiliary to financial intermediation
47	70	Real estate services
48	71	Renting services of machinery and equipment without operator and of personal goods

Source: own elaboration from WIOD data (WIOD, 2013).

Table A.6. (Continuation) WIOD products

Number	WIOD code	Product
49	72	Computer and related services
50	73	Research and development services
51	74	Other business services
52	75	Public administration and defence services
53	80	Education services
54	85	Health and social work services
55	90	Sewage and refuse disposal services, sanitation and similar services
56	91	Membership organisation services n.e.c.
57	92	Recreational, cultural and sporting services
58	93	Other services
59	95	Private households with employed persons

Source: own elaboration from WIOD data (WIOD, 2013).

Table A.7. WIOD energy products

Number	Energy product group and energy product
1	Coal: hard coal and derivatives, lignite and derivatives, coke
2	Crude and feedstock: crude oil and feedstock
3	Petroleum products: diesel oil for road transport, motor gasoline, jet fuel, light fuel oil, heavy fuel oil, naphtha, energy other petroleum products
4	Gases: natural gas, derived gas
5	Renewables and wastes: industrial and municipal waste, bio-gasoline including hydrated ethanol, bio-diesel, bio-gas, other combustible renewables
6	Electricity and heat: electricity, heat, nuclear, hydroelectric, geothermal, solar, wind power, other sources

Source: own elaboration from WIOD data (WIOD, 2012).

Table A.8. WIOD air emissions

Number	Emissions group, air emissions
1	Greenhouse gas emissions, needed to de rive Global Warming Potentials: CO_2 (carbon dioxide), CH_4 (methane), N_2O (nitrous oxide)
2	Emissions of acidifying substances, needed to derive Acidification Potentials: NO_X (nitrogen oxides), SO_X (sulphur oxides), NH_3 (ammonia)
3	Emissions of substances potentially causing Tropospheric Ozone Formation: CO (carbon monoxide), NMVOC (non-methane volatile organic compounds), CH_4 (methane), NO_X (nitrogen oxides)

Source: own elaboration from WIOD data (WIOD, 2012).

Table A.9. WIOD materials

Number	Material
1	Animal biomass (used-unused)
2	Feed biomass (used-unused)
3	Food biomass (used-unused)
4	Forestry biomass (used-unused)
5	Other biomass (used-unused)
6	Coal (used-unused)
7	Natural gas (used-unused)
8	Crude oil (used-unused)
9	Other fossil fuels (used-unused)
10	Non-metallic minerals for construction (used-unused)
11	Other non-metallic minerals (used-unused)
12	Metals (used-unused)

Source: own elaboration from WIOD data (WIOD, 2012).

Table A.10. WIOD types of land

Product number	Type of land
1	Arable land
2	Permanent crops
3	Permanent meadows and pastures
4	Productive forest area

Source: own elaboration from WIOD data (WIOD, 2012).

Table A.11. WIOD types of water

Product number	Type of water
1	Blue water
2	Feed Green water
3	Grey water

Source: own elaboration from WIOD data (WIOD, 2012).

A.3. Multi-region versus single-region setting

The world input-output tables available in WIOD are multi-regional tables that contain information about several countries. On the contrary, ISTAT tables follow a single-region setting. The main difference between a multi-regional and a single-region framework is how data on imports and exports are presented and disaggregated. Anyway, since imports and export are also part of domestic technical processes and of the final value of domestic products, different ways of record them can lead to different information about total output.

To illustrate how different tables' structures show different information, let's analyze a simplified example. Let us consider a world composed by two countries *r* and *s* and two sectors *i* and *j* in each country. Figure A.1 and Figure A.2 show, respectively, how data are recorded in a multi-regional setting such as WIOD or in a single-region setting such as ISTAT tables.

The input-output table represented in Figure A.1 shows the main blocks of a multi-regional table. Matrix **Z** records the inter-country, inter-industry deliveries: focusing for example on country *r*, $\mathbf{Z}^{\mathbf{rr}}$ represents the inter-industry deliveries within the country, $\mathbf{Z}^{\mathbf{rs}}$ the products that the country *r*'s sectors export to country *s*'s sectors, while $\mathbf{Z}^{\mathbf{sr}}$ shows the inputs that the country *r*'s sectors import from country *s*'s sectors. Matrix **Y** contains the final demand: the vector $\mathbf{y}^{\mathbf{rr}}$ shows the goods produced in country *r* and consumed as final products in the same country, $\mathbf{y^{rs}}$ shows the final goods country *r* is exporting to country *s*, and $\mathbf{y^{sr}}$ shows the final products consumed in country *r* and imported from country *s*. The horizontal sum of **Z** and **Y** (shown in the vector **x**) represents the gross output, what each sector of each country is producing. The value produced by each sector has to be equal to the sector's inputs used, represented by the vertical sum of matrix **Z** and the transposed vector $\mathbf{v}'$ that describes the sector value added.

Figure A.1. Input-output table, WIOD-type multi-regional setting

		Z				Y		x
		r		s				
		sec i	sec j	sec i	sec j			
r	sec i	Z^{rr}		Z^{rs}		y^{rr}	y^{rs}	x^{r}
	sec j							
s	sec i	Z^{sr}		Z^{ss}		y^{sr}	y^{ss}	x^{s}
	sec j							
	v'	$v^{r\prime}$		$v^{s\prime}$				
	x'	$x^{r\prime}$		$x^{s\prime}$				

Note: c countries (r, s), n sectors (i,j).
Source: own elaboration.

The input-output table represented in Figure A.2 shows the basic structure of a single-region table. The main blocks are the same as the multi-regional table: the matrix $\mathbf{Z_t}$ describing the inter-industry deliveries, the vector $\mathbf{y_t}$ containing the final demand, and the transposed vector $\mathbf{v}'$ containing the value added for each sector. Anyway the content is different. Indeed, the inter-industry delivery matrix $\mathbf{Z_t}$ contains all the inputs used by sectors *i* and *j* in country *r*, without distinguishing between domestic or imported inputs. In the same way, the final demand $\mathbf{y_t}$ includes the domestic final demand satisfied through domestic products, the domestic final demand for foreign products, and also all kind of exports, without distinguishing between intermediate or final products exported. The total output vector $\mathbf{x_t}$, horizontal sum of $\mathbf{Z_t}$ and $\mathbf{y_t}$, does not show, as in the previous case, the total production of each sector, but the total resources available, including imports. Imports are included also in the vertical sum that in this case represents the total uses of each sector in country *r*. The transposed vector $\mathbf{m_t'}$ of total import by sector is also added to the vertical sum, to offset any imbalance in the input-output table. As shown in Figure A.2, the ISTAT-type tables often offer an input-output table also for imports, distinguishing between import of intermediate demand and import of final demand, and allocating them to the different sectors and final demand components.

Figure A.2. Input-output table in a ISTAT-type single-region setting

		$\mathbf{Z_t}$			
		r			
		sec i	sec j	$\mathbf{y_t}$	$\mathbf{x_t}$
r	sec i	$Z^{rr}+Z^{sr}$		$y^{rr}+y^{rs}+y^{sr}+(Z^{rs})l$	x_t^{r}
	sec j				
	$\mathbf{v'}$	$v^{r'}$			
	$\mathbf{m'_t}$	$l'(Z^{sr})+y^{sr'}$			
	$\mathbf{x_t'}$	$x_t^{r'}$			

		Import			
		r			
		sec i	sec j	$\mathbf{y_m}$	$\mathbf{m_t}$
r	sec i	Z^{sr}		y^{sr}	m_t^{r}
	sec j				

Note: Country r, n sectors (i,j).
Source: own elaboration.

Annex B. Acronyms and chemical symbols

CBTA	Carbon-motivated Border Tax Adjustment
CH_4	Methane
CO_2	Carbon Dioxide
DTA	Domestic Technology Assumption
EC	European Commission
ETD	Energy Tax Directive
ETS	Emissions Trading System
EU	European Union
GHG	Greenhouse gas
GTAP	Global Trade Analysis Project
GWP	Global Warming Potential
HICP	Harmonized Index of Consumer Prices
IPCC	Intergovernmental Panel on Climate Change
ISTAT	Italian National Statistical Institute
MRIO	Multi-Regional Input-Output
N_2O	Nitrous Oxide
NAMEA	National Accounting Matrix Including Environmental Accounts
NH_3	Ammonia
NO_X	Nitrogen Oxides
PAE	Potential Acid Equivalent
SDA	Structural Decomposition Analysis
IOT	Input-Output Tables
SO_X	Sulphur Oxides
SUT	Supply and Use Tables
UNFCCC	United Nation Framework Convention on Climate Change
US	United States
WIOD	World Input-Output Database
WTO	World Trade Organization