Universidade de Aveiro Departamento de Economia, Gestão e Engenharia Industrial
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MARGARITA MATIAS ROBAINA ALVES

EFEITOS DE UMA REFORMA FISCAL ECOLÓGICA EM PORTUGAL – ANÁLISE DE EQUILÍBRIO GERAL

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EFFECTS OF A GREEN TAX REFORM IN PORTUGAL – A GENERAL EQUILIBRIUM ANALYSIS

Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Doutor em Economia, realizada sob a orientação científica do Doutor Egas Manuel da Silva Salgueiro, Professor Auxiliar do Departamento de Economia, Gestão e Engenharia Industrial da Universidade de Aveiro e da co-orientação científica do Doutor Miguel Rodríguez Mendez, Professor do Departamento de Economia Aplicada da Universidade de Vigo.

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palavras-chave

Reforma Fiscal Ecológica, Duplo Dividendo, Licenças de Emissão de CO2, Mercado Europeu do Carbono, Impostos Ambientais, Modelos de Equilíbrio Geral

Resumo

Do ponto de vista da política económica, existe a possibilidade de utilizar a receita dos impostos ambientais para baixar os impostos sobre o trabalho, promovendo assim o emprego. Esta oportunidade surge na literatura como forma dos países industrializados responderem a um duplo desafio: um crescente nível de poluição e um decrescente nível de emprego. Alguns países tomaram já decisões no sentido de alcançar o “duplo dividendo”: melhorias ambientais e diminuição do desemprego. Os resultados teóricos, na sua maioria cépticos em relação à verificação do segundo dividendo, são substancialmente contrariados por uma série de estudos que utilizam modelos de equilíbrio geral. Pretende-se com este trabalho fazer uma simulação para a economia portuguesa de uma reforma fiscal ambiental com as características referidas e a verificação da existência do “duplo dividendo”, através de um modelo computacional de equilíbrio geral.

Para além disso, é feita uma análise dos impactos do Mercado Europeu de Licenças de Emissão, ao nível sectorial e regional, em Portugal, utilizando dados microeconómicos, com o objectivo de estudar as consequências ao nível das trasacções entre sectores e efeitos distributivos entre regiões.

Keywords

Green Tax Reform, Double Dividend, tradable CO2 permits, European Carbon Market, Environmental Taxes, General Equilibrium Models

Abstract

A discussion has arisen amongst economic policy-makers, about using the revenue of environmental taxes to lower labor taxes, thus improving employment. This possibility appears in literature as an answer to a double challenge facing industrialized countries: the increasing level of pollution and decreasing level of job creation. Some countries have already taken decisions in the direction of the “double dividend”: environmental improvements and reduction of unemployment. The theoretical results, mostly skeptical to this second dividend, are substantially opposed by empirical studies that use general equilibrium models. The goals of this work are to make a simulation for the Portuguese economy of a Green Tax Reform with the referred characteristics and to verify the “double dividend” hypothesis, through a computational general equilibrium model.

An analysis of the impacts of the European Carbon Market is also made, both at the sectoral and regional level, in Portugal, using micro data, with the objective of studying the consequences on the transactions between sectors and the distributive effects between regions.

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List of Acronyms

CCGT – Combined Cycle Gas Turbine

CNR – Final Consumption made by non-residents

COP – Conference of Parties

ECM – European Carbon Market

EPBD – Energy Performance in Buildings Directive

EU – European Union

EU ETS – European Union Emission Trading System

EUA – European Union Allowances

GDP – Gross Domestic Product

GDPbp – Gross Domestic Product at basic prices

GDPpa – Gross Domestic Product at acquisition prices

GEM – General Equilibrium Models

GHG – Greenhouse Gases

GTR – Green Tax Reform

GVA – Gross Value Added

INE – Instituto Nacional de Estatística

IOST – Input Output Symmetric Table

LULUCF – Land Use, Land-use Change and Forestry

NAP – National Allocation Plan

NAP II – Second National Allocation Plan

NPISH – Non-profit Institutions Serving Households

PNAC – National Program for Climate Change

PNAER – National Action Plan for Renewable Energy

SABI – Iberian Balance Sheet Analysis System

SAM – Social Accounting Matrix

SSC – Social Security Contributions

1. Introduction

1.1. Motivation: Climate Change, Kyoto Protocol and Environmental Policies

In the last years the expressions "Climate Change" and "Global Warming" appear daily in the news and are used by environmentalists, academics and politicians as very imperative issues. It is important to clarify them, because they are often used to express the same idea[1].

Climate change may refer to any important change in climate (temperature, precipitation, or wind) that subsists for a long period of time (decades or longer). These changes may result from natural factors (such as changes in the sun's intensity or slow changes in the Earth's orbit around the sun), natural processes (e.g. changes in ocean circulation) and human activities that change the atmosphere's composition (e.g. through burning fossil fuels) and the land surface (e.g. deforestation, reforestation, urbanization, desertification, etc.).

Global warming is an average increase in the temperature of the atmosphere near the Earth's surface and in the troposphere, which can contribute to changes in global climate patterns. Global warming can occur from a variety of causes, both natural and human induced. In common usage, global warming often refers to the warming that can occur as a result of increased emissions of greenhouse gases (GHG) from human activities.

Most meteorologists and climate scientists consider that human action has a very important effect on these phenomena. The Intergovernmental Panel on Climate Change (IPCC, 2007) says that great part of the heating observed during the last 50 years is due to a greenhouse effect[2], caused by the increase of the concentrations of GHG originated by a more

[1] See http://epa.gov/climatechange/basicinfo.html for some definitions.

[2] "Greenhouse gases effectively absorb thermal infrared radiation, emitted by the Earth's surface, by the atmosphere itself due to the same gases, and by clouds. Atmospheric radiation is emitted to all sides, including downward to the Earth's surface. Thus, greenhouse gases trap heat within the surface-troposphere system. This is called the greenhouse effect." In IPCC (2007).

intensive use of underground and ground water in agriculture, by a stronger energy consumption and by the increase in manmade pollution.

Total annual emissions of GHG have been rising steadily. Over the last three decades, GHG emissions increased by an average of 1,6% per year, with carbon dioxide (CO2) emissions from the use of fossil fuels growing at a rate of 1,9% per year (IPCC, 2007). The effects of this pollution can lead to unsustainable development with important consequences for humans and for natural resources (namely through global warming, as referred above).

The world conscience that we have environmental common problems, problems that countries must try to solve together, was revealed explicitly for the first time in 1979, with the First World Climate Conference. Then, the Toronto Conference on the Changing Atmosphere followed in Canada 1988, where IPCC recognized for the first time the existence of a climate change problem.

After that appeared the IPCC's First Assessment Report, in Sweden 1990, and the United Nations (UN) Framework Convention on Climate Change, in ECO-92 in Brazil, which started to be effective in March 1994. During this last conference it was shown that, in developed countries, some measures were being taken to control environmental damages, but in developing countries the economic growth has monopolized all priorities, while the environment has been degraded.

To invert this situation, the UN convention had the objective of stabilizing the concentrations of GHG at a level that would prevent anthropogenic dangerous interferences in the climatic system and reduce the existing social and economic inequalities between developed countries, developing countries and even underdeveloped countries. For that purpose, it establishes common but differentiated responsibilities, distinguishing between developed and developing countries. Developed countries were pointed as being, historically, the main contributors to the GHG emissions and global warming.

In 1997, the Kyoto Protocol was signed (but started to be effective only in 2005[3]), proposing a calendar to GHG reduction. The detailed rules for the implementation of the Protocol were adopted at 7th Conference of the Parties (COP 7) in Marrakesh in 2001, and are called the "Marrakesh Accords."

OECD members (or developed) countries and ex-Soviet bloc integrating countries, denominated "countries in transition to a market economy", compose the Annex B of the Protocol. These countries committed voluntarily and formally to reduce their GHG emissions[4] to at least 5,2% below the 1990 levels , in the period 2008-2012, as well as to help, financial and technically, the developing countries to adopt "clean" technologies in power and industrial sectors. Particularly, the European Union (EU) parties agreed to reduce its emissions by 8% in the period 2008-2012 in comparison with 1990 levels.

Also, all the countries are committed to formulate and to manage national plans on reducing climate change, as well as to make and present to the Convention updated periodic inventories of their sources of emissions and their carbon drains.

The Protocol rules were not symmetrical. In order for the EU to reach its goals of reduction, it was made an agreement in 1998 to divide the responsibility of reduction of GHG in an unequal way among the Member States. This method took care of diverse variables like historical income per capita, GHG emissions, the chances for reducing these, the level of economic development, the energy mix, the industrial structure, etc. It is known as "the burden sharing agreement".

3 This delay in its effectiveness was due to the requirement of its ratification by industrialized countries responsible for at least, 55% of CO2 emissions, fact that only happened in 2005, with the ratification of Russia, responsible for 17% (EU for 36%). On the other side, the United States and Australia governments denied to sign the Protocol, invoking competitiveness and economic reasons.

4 Kyoto Protocol covers the following GHG: carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), hydrofluorocarbons (HFC), per fluorocarbons (PFC) and sulphur hexafluoride (SF6).

The distribution of the responsibilities varies a lot, as we can see in table 1[5]: Luxembourg must reduce its emissions by 28%, whereas Portugal can increase its emissions by 27%.

Table 1 - Burden-sharing target of the EU – Target 2008-2012

EU 15 – Countries	Emissions allowed above 1990 level (%)
Austria	-13
Belgium	-7,5
Denmark	-21
Finland	0
France	0
Germany	-21
Greece	25
Ireland	13
Italy	-6,5
Luxembourg	-28
Netherlands	-6
Portugal	27
Spain	15
Sweden	4
UK	-12,5
EU 15 Kyoto target	-8

Source: Climate Action Network Europe in http://www.climnet.org/resources/euburden.htm. Per decision of EU Environment Council 16th June 1998. Reaffirmed by joint ratification of the Kyoto protocol on May 31st 2002.

The Protocol also previews some flexible mechanisms like Joint Implementation, Mechanism of Clean Development and Emission Trade System.

The first one gives to any country with an emission reduction commitment (Annex B Party), the possibility of obtaining emission reduction units through investing in emission reduction projects in another Annex B Party. Joint implementation offers Parties a flexible and cost-efficient

5 For a discussion about the way "Burden Sharing" should be allocated see Verdestal & Svendsen (2004) or Posner & Sunstein (2008).

means of fulfilling a part of their Kyoto commitments, while the host Party benefits from foreign investment and technology transfer.

The Mechanism of Clean Development allows that an Annex B Party executes a project of reduction of emissions in developing countries, like Latin American countries. With such projects they can gain sealable emission reduction credits, each one equivalent to a ton of CO2 that can be counted for its Kyoto goal. It's a flexible instrument to reduce the emissions, stimulating sustainable development and the reduction of emissions.

Annex B Parties can also use the Emission Trade System as an instrument to fulfil its Kyoto target. This scheme allows countries to sell credits, if their emissions are bellow the target, or buy credits if they are over their targets.

So, by this Protocol, each country is free to choose the best way to reduce its GHG emissions. But beyond the Kyoto mechanisms, which other instruments can support countries in reaching these goals for GHG emissions? We can refer to taxes, permit markets and command and control instruments.

Environmental problems are, mostly, a consequence of polluting agents not having to support the costs of its actions. According to Coase Theorem, if the agents involved in externalities are able to negotiate (without transaction costs), and there are property rights well defined by the State, an agreement where the externalities are internalized may be reached.

Accordingly, if negotiation is possible, it can lead to the inclusion of emissions costs in the decisions of the polluting agent. If the negotiation is not practicable, then it can be possible for the government to reach a similar result through the imposition of a tax on the polluting agent, whose amount represents the value of the externality caused. This idea was presented by Arthur Pigou in 1920[6], being these taxes frequently cited as Pigou taxes.

[6] (Pigou, [1920] 1932)

These taxes correct price distortions in the market, incorporating the environmental costs of the emissions (and other costs) into the market prices – they correct prices and apply the "polluter pays principle"[7].

More recently it has been proposed the introduction of a system of emission-permits instead of pollution taxes. An emission-permit system is a pollution-control instrument based on requiring pollution sources to hold transferable permits. It is frequently called a "cap and trade" system.

The regulator issues the desired number of permits ("cap"), that is, the limit for the emissions of the pollutant. The companies or other groups have to hold emission licenses that give them the right to emit the respective pollutants. The total sum of licenses cannot exceed the "cap", limiting the emissions to this sum. Each source designs its own compliance strategy, including sale or purchase of allowances and pollution abatement. The companies who need to increase its emissions beyond the credits will have to buy licenses to the ones that pollute less. In such a way, the purchasers will pay a charge for polluting, while the sellers will be rewarded by having reduced the emissions beyond what was demanded.

Price-driven instruments, like taxes and tradable quotas, allow flexibility in how, where and when emission reductions are made, giving chances and inducements to minimize the cost of mitigation (static efficiency). For instance, an emission tax gives to the producers, who know their technology better, the incentive to choose the cheaper method of pollution control: reducing the production; changing the technology; using a different fuel, as natural gas instead of coal; introducing methods of pollution control to remove the pollutants of the emissions; dislocating the production process to a less sensible localization, etc.

Moreover, taxes and transferable quotas allow the producers with lesser costs of reducing pollution to make a bigger adjustment that the ones with higher costs. In such a way, the total cost of reduction of the pollution can be minimized. Additionally, these instruments have dynamic efficiency, as they give continuous incentives for the reduction of the pollution and for technological innovation (OECD, 1997). Thus the

[7] See European Environment Agency (1996) and Hodge (1995) for advantages of environmental taxes in pollution control.

incentives created by price-driven instruments ensure that the policymaker’s environmental goals are achieved at the lowest possible cost for the whole economy.

Finally, considering that producers and consumers will not abandon the regulated activities, taxes and tradable quotas will increase public revenues (in the case of tradable quotas, this will only happen if they are auctioned quotas). These can be used directly to solve environmental problems or to subsidize producers and/or consumers to modify its environmental behaviour; they can still be applied in other government projects, allowing that other taxes, for instance, labour taxes, are reduced.

1.2. Green Tax Reform and Double Dividend: definitions and European experience

In the last years, industrialized countries maintained a high and increasing level of unemployment and, at the same time, they faced serious and persisting environmental problems. The perception of these two realities brought the politicians and academics to debate the idea that environmental taxes could be used to simultaneously improve the environmental quality and to diminish the rate of unemployment.

In 1992, the European Commission presented proposals, with the main objective of introducing a tax on energy and carbon dioxide emissions to stabilize the CO2 emissions, until the year 2000, at their level of 1990. This measure was considered as a key element of world-wide policies destined to reduce emissions of GHG and to fight global warming. A secondary objective consisted of assuring a general economy of energy: this was one of the reasons why the tax was designed to fall partly on CO2 emissions and partly on the energy content. Finally, the proposal was considered an integrant part of a global policy of fiscal reform.

Since fiscal neutrality was intended, revenues could be used to reduce other taxes - namely to substitute labour taxation, thus producing some non-environmental benefits as well (employment, efficiency, etc), known in the literature as the double dividend of environmental taxes. However, this proposal was rejected by some countries. Anyway, many OCDE countries have been implementing environmental taxes since the middle of the 80's and Green Tax Reforms (GTR) were introduced in the following context: the distortive taxes on labour and capital have been reduced and environmental taxes were increased or introduced. Particularly, many governments have reduced the labour taxes (in particular non-wage labour cost) with the aim of reducing unemployment.

This substitution of taxes lead to a "double dividend" as, in one hand, it improves the environment and, on the other hand, it diminishes the unemployment and/or increases the economic efficiency. The taxes on environment harmful activities don't distort the economic decisions, but, on the opposite, they correct the existing distortions. Environmental taxes discourage activities that provoke economic public losses, and, as such, they do not impose any "deadweight loss", but provide revenues and economic profits. These can be used to reduce other taxes that have a "deadweight loss", namely the Social Security Contributions (SSC). So, it becomes easier to implement an environmental reform, as its aims go beyond the environmental protection.

Therefore, it is not surprising that the European Commission presented in April 2011 a proposal that resembles the GTR implemented in some European countries[8]. The European Commission pursues two main goals: (i) to contribute to growth and employment by shifting taxation from labour to consumption, (ii) to promote energy efficiency and consumption of more environmentally friendly products. Furthermore, the proposal aims to complement the existing EU ETS by applying a CO2 tax to sectors that are out of its present scope (transport, households, agriculture and small industries). If approved, this will result in a sort of hybrid regulation system for CO2 emissions, thus ameliorating some of the efficient concerns raised previously.

The proposal includes splitting the minimum energy tax rate into two elements: on one hand a CO2 emission tax for each energy product equal to €20 per tonne of CO2; on the other hand, another tax based on its energy content, i.e. measured in Gigajoules (GJ). As a result of both elements the minimum tax rate would be fixed at €9.6/GJ for motor fuels, and €0.15/GJ for heating fuels. This will apply to all fuels used for transport and heating.

8 European Commission (2011).

The proposal considers also some sort of social aspects and transitional periods which are taken into account for improving political acceptance. As a result the Member States might exempt from taxation energy consumed by households for their heating and the transitional periods for the full alignment of taxation of the energy content might last until 2023.

Alternative definitions have led to some confusion in the debate on the double dividend. European authors define the second dividend usually as an increase in employment (Ligthart & van der Ploeg, 1996). American authors define the second dividend in terms of a reduction in the distortive cost of the tax system (L. H. Goulder, 1995; Parry, 1995).

There are mainly two different approaches to the double dividend hypothesis: the “environmental” approach and the “public finance” approach.

The first one, supported by Tullock (1967), Terkla (1984), Lee and Misiolek (1986) and Pearce (1991), is based on the idea that the environmental taxes give extra benefits, because they are the best way to control pollution and because they increase efficiency, as long as revenues are used to diminish distorting taxes. This approach uses partial equilibrium models to explain its results, ignoring, in this way, that the interaction of environmental taxes with other taxes can amplify some efficiency losses[9]. Furthermore, it does an incomplete and ambiguous characterization of the two dividends.

The “public finance” approach, developed mostly in the 90’s (see Bovenberg and Goulder (2002) for a survey), focus on the second dividend, that is, the efficiency gains or losses of the fiscal system after introducing environmental taxes. Using General Equilibrium Models (GEM), it allows a complete characterization of the two dividends to be made: the first one covers the variations of welfare related with the environment, as it reduces the externalities associated with pollution; the second one focus its attention on variations occurring in non environmental welfare.

There are alternative definitions, as can be seen in Goulder (1995). This author distinguished three definitions of double dividend: (i) in the

[9] See for instance Bovenberg and Goulder (1997)

weak form: the use of revenues of environmental taxes to finance reductions in a distortive tax, originates cost savings “vis-à-vis” the case where the revenues returned to households under lump-sum transfers; (ii) in the intermediate form: it is possible to find at least a distortive tax that can be substituted by an environmental tax at null or negative costs; (iii) in the strong form: it’s possible to substitute any distortive tax at null or negative costs.

Giménez & Rodríguez (2010) criticize the “public finance” approach, saying that it overestimates the efficiency costs of the GTR, linking the second dividend to the efficiency costs of the GTR and including the primary costs of the reform as part of the variations of non environmental welfare (primary costs are the costs of reducing inefficient levels of emissions and consumption, that according to authors, would not have to be seen as efficiency costs). So, they consider an alternative definition in which the first dividend has to do with net benefits in welfare after applying or increasing environmental taxes, when the revenues are returned to the families by lump-sum transfers. The second has to do with the resultant variations of welfare in reduction of distortive taxes instead of lump-sum transfers. This definition exceeds the Goulder definition of strong and weak double dividend, because it concentrates on its signal. It has a relevant policy implication as it establishes a criterion to apply only the environmental tax, or alternatively using its revenues to diminish a distortive tax. It avoids confusion between economic and efficiency costs and simplifies the computation of the two dividends.

Based in the existing literature and some empirical evidence about double dividend, some EU Member States have separately looked for solutions for the CO2 emissions problem and some countries have shown a large effort in developing GTRs in the last years. It is complicated to make ex-post evaluations of these experiences and from there to derive clear rules to attain the double dividend. The environmental taxes seem to raise good results in economic and environmental grounds, but a small number of evaluations of its effectiveness have been made, because the environmental taxes are used in concurrence with other instruments of environmental policy.

Next we present a resumed version of some GTR experiences[10]. In some cases we also present simulations[11] and results for these countries.

Sweden

In 1991, Sweden was one of the first countries in Europe to implement a GTR. The main objective was to reduce some distortive taxes on labour, personal income and employers' SSC. To keep the tax revenue constant, some indirect taxes were increased, some new environmental taxes were introduced, as the tax on the carbon-energy (with some exemptions for energy-intensive industries), and some taxes were increased, like the tax on diesel, the tax on the electricity, and taxes on fertilizers, pesticides, aerial traffic, batteries, etc.[12]

The Swedish Green Tax Commission analyzed the effect in employment of an increase of the tax on CO2, coupled with a reduction on labour taxes, using a GEM. The conclusions point to a loss of welfare, due to a reduction of the real income. This loss does not include the environmental gain. Between the companies, there were different winners and losers. The winners are in sectors such as telecommunications and medicines. The losers are companies of paper, transports and sectors of retail (European Environment Agency, 1996; Brännlund & Kriström, 1999).

Denmark

Denmark implemented an environmental reform in 1993. The main objective was to reduce the taxes in all income sources and gradually change the tax burden from labour and capital to pollution and the use of scarce natural resources (Danish Ministry of Finance, 1995). Taxes on fossil fuels, electricity and waste were increased. Since 1995, new environmental taxes on the use of energy by the industries (i.e. taxes on CO2 and SO2) were introduced. All the income from these taxes was recycled again for the industry, like subsidies for investments whose aim is energy saving and cuts in the SSC of the workforce.

In 1998 an evaluation was made of the results attained with this policy and it concluded that this policy contributed to a reduction of the CO2

[10] See Gago, Labandeira and Rodríguez (2003), Hoerner and Bosquet (2001) or Gago & Labandeira (2011) for a detailed analysis of recent GTR experiences.
[11] For more GTR simulations see for instance Majocchi (1996), Proost and van Regemorter (1995), Bovenberg and Goulder (1997), Hayden (1999) or Labandeira, Labeaga, and Rodríguez (2004).
[12] Source: Swedish government (2003)

emissions in about 4% in 2005 (OECD, 2000). The Inter-ministerial Dithmer Committee calculated the impact of the unilateral increase of the tax on CO2 in the industries and concluded that a positive impact in the employment existed, in the order of 1000 new jobs, at the same time that a reduction of 5% in CO2 emissions was obtained. The revenues of these taxes would be recycled for the reduction of SSC and also for subsidies to the investment (European Environment Agency, 1996).

Netherland

Between 1971 and 1996, the Dutch tax structure and environmental taxes evolved from a simple redistributive system to an "ecological" tax system. From 1996 a new tax on energy has been put into practice in small scale to the consumers (families, small commercial establishments, etc.). These revenues were recycled for the families through reductions on income tax and on workers SSC (OECD, 1997; European Environment Agency, 1996).

In 1994 it was estimated (Dutch Commission for Greening the Fiscal System, 1996) that the tax on CO2, existing since 1980, reduced the level of emissions in about 1%. Vermend and Van der Vaart (1998) and Komen and Peerlings (1999), used GEM to evaluate the effects of the environmental policies in this country. The first ones simulated an increase on energy tax, and a reduction of the price of labour insurance. The results showed a little deterioration in the industrial competitiveness and a reduction in private consumption, exportations and Gross domestic product, due to an increase on prices and a reduction in tax revenues (given that the tax base was reduced, as there was a trend to save energy). This was reflected in a little fall on the employment rate.

The second simulation had more positive results, distinguishing two kinds of energy tax: one for small users and another for all the industries. In both simulations the tax revenues are used to reduce labour taxes. In the case of the tax for small users, both welfare and employment increase, verifying the double dividend. The difference is that this simulation considers more than one production factor, what allows the environmental tax to alleviate the inefficient distribution of the tax weight between factors, as there is a redistribution of the factors most taxed to the factors less taxed. In the general tax, the conclusions are basically the same, with a small reduction in welfare.

Germany

Germany adopted a law, in April of 1999, with the objective of making energy more expensive. Five steps of tax increases were taken on the main transport fuels (oil and diesel) and in other energy products; a tax on electricity was also introduced. Special tax conditions were given to some industries, agriculture, fishery and forestry, and factories employing disabled people. The GTR in Germany increased the total value of energy taxes from 34.1 billion Euros in 1998 to around 52.7 billion – an increase of 55 percent, from 1999 to 2003. The proportion of taxes levied on the factor 'environment' increased from 8.0 percent in 1998 to 9.7 percent in 2003 (Green Budget Germany, 2006). The revenues were used to diminish the employee's and employer's SSC (OECD, 2000).

Bach, et al. (2002) analyzed the impact of the GTR in Germany, using two models (macroeconometrical and a GEM). The macroeconomic results are also linked to a microeconomic model in the family sector, in order to study the effects on the distribution of income. They verify a small "double dividend" as CO2 emissions diminish and employment increases. The impact on economic growth is found to be minimal. The fear that the environmental fiscal reform might interfere with the goals of social and income-distribution policy is found to be largely unjustified.

Norway

Norway applies since 1992 a GTR project, with the existence of two taxes on carbon/energy: a general tax on fuels and a tax for small users covering gasoline and electricity. The first one covers all energy inputs and taxes fall 50% on the carbon content and 50% on the energy value. These taxes are relatively low, but reductions or exemptions are practically inexistent. Revenues are used to reduce the income tax, to stimulate investments that provide energy savings for the families and companies and to pay compensations to the companies (OECD, 2000).

A study made for the Central Planning Bureau (1992), showed a clear effect on the competitiveness if the tax fell on the energy-intensive industries and also showed some differences between the macroeconomic effect of an unilateral application of the tax on Norway and of a common application of the tax on the OCDE countries, as the production and labour in the energy intensive industries could change location to other countries of the OCDE, for instance. For the period of 1991-1993, Larsen and Nesbakken (1997) found a reduction of CO2 emissions in about 3-4%. In the particular case of paper industry, the oil consumption would have been 21% higher if the tax did not exist. For the sector of intermediate products and for government services the oil consumption would have been 11 and 10% higher.

Finland

Finland adopted the GTR in 1989, cutting income tax and SSC, raising energy taxes and introducing new environmental taxes (OECD, 1997; European Environment Agency, 1996). In January of 1990 a CO2 tax based on the carbon content of fossil fuels was introduced. The tax rate evolved from €1,12/t CO2 in 1990 to €20/t CO2 in 2010 (Green Budget Europe, 2011). Some deviations existed: natural gas met a reduced rate, and peat was exempted in 2005-2010. In 1994-1996 a combined surtax base of carbon+energy content was applied (Green Budget Europe, 2011).

In 1998, the Finnish government approved a new package of GTR, with reduction of SSC, on one side, and, on the other, the incorporation of a Landfill Tax and a change in energy taxation (namely an increase on electricity tax of about 25%). The tax on CO2 emissions also had a similar increase and was imposed only on traffic fuels and heating fuels. Other approved measures were a high tax deduction for Aeolian and waste energy, the maintenance of the deductions for wood production and for electricity generated by its combustion and for heat and power engines (Gago, Labandeira and Rodríguez, 2003).

In January 2011 a reform was introduced in such a way that liquid fuels and coal are taxed, not only according to their energy and CO2 content, but also with regard to their emissions into the local environment, which have adverse health effects. Furthermore, the CO2 component is now based on a lifecycle approach instead of combustion emissions only (Green Budget Europe, 2011).

Two studies had been used to review the environmental policies in Finland: the KESSU IV model of the Ministry of Finance and the University of Oulu's FMS model. Both models predicted that imposing a CO2 tax and recycling the revenues through reductions in personal income tax would negatively affect the Finnish economy on virtually all counts. These impacts would be smaller if revenue recycling happened through cuts in employers' SSC or in VAT (Finnish Ministry of the Environment, 1994).

Italy

In 1999 a new tax on CO2 emissions was introduced. The GTR was based on two components: (i) a gradual adjustment of the indirect taxes on mineral fuels, since 1999 to 2005, in accordance with its use and with their amount of carbon; (ii) the introduction of a tax on consumption of coal, fuels and natural bitumen, used in the incinerators, as foreseen in the directive of CE 88/609. The revenues of these taxes would be used the following way: 60,5% for reductions in workers SSC; 31,1% for compensation measures; and 8,4% for interventions to improve the efficiency in energy use (OECD, 2000).

Ireland

After the financial crisis that the Irish government faced in 2010, the GTR was singled as a way to raise considerable revenues to assist the country in its efforts to rebalance the budget.

Professor Frank J. Convery from University College in Dublin published some comments on the potential of new environmental taxes in Ireland. He looked at the impacts of levies on water, aggregates and packaging, taxes on land value and reformed taxes on GHG. He pointed out that "given that Ireland has to raise taxes anyway, it makes sense to raise them in ways that simultaneously improve environmental quality, provide incentives for new low carbon enterprise, ensure managing resources efficiently, help meet EU obligations, apply the polluter pays principle, and that allow other taxes that damage economic performance to be reduced or at least limit the extent of the rise" (Convery, 2010).

In order to increase state revenue, Ireland introduced the carbon tax at a rate of 15 Euros per ton in the 2010 Budget. The price of carbon will be doubled to 30 Euro per tonne until 2014, thereby contributing 330 million Euros to the overall correction. On the other side, and to compensate the living standards of citizens, the corporation tax will remain untouched at 12,5% (Green Budget Europe, 2010b).

Estonia

A phased GTR was approved in Estonia in 2005. The first phase, in 2006-2008, and the second one in 2009-2013. The reform designed a gradual increase of taxes on emission, natural resources and fuels for transportation. Furthermore, it was introduced a tax on natural gas and electricity. The tax revenues were recycled through personal income tax reduction (Gago & Labandeira (2011)).

Czech Republic

Czech Republic also approved a phased GTR in 2007. The first phase, begun in 2008 and used the revenues from new energy taxes to reduce SSC. In the second phase, planned for 2009-2010, a new tax on CO2 emissions was introduced. The third phase, programmed to begin after 2012, is pending of diverse parliamentary proceedings (Gago & Labandeira (2011)).

Beyond particular cases of GTR, we present now some recent trends in this issue, for European countries, in particular the evolution of environmental taxes and labour taxes levels, taking as reference European Commission (2010) data and conclusions.

This report shows that the share of environmental taxes in total tax revenue is decreasing for the EU-27 as a whole, reaching 6,1% in 2008 (from 6.8% in 2000). At the same time, the share of taxes on labour also decreased slightly (from 50.1% in 2000 to 50.0% in 2008). However, this does not hold in all Member States and some of them (Bulgaria, Denmark, Estonia, Poland) have increased the share of environmental taxes while decreasing taxes on labour.

Although these experiences have different designs, they all have common points: the introduced or increased environmental taxes were essentially taxes on energy or in CO2 emissions; they were all revenue neutral, that is, all revenues from environmental taxes were recycled back to the economy. However, we can see some discrepancies in the diversity of environmental taxes used and in the time frame of GTRs.

EEA technical report (European Environment Agency, 2005) presents some lessons to learn from these GTR experiences, namely: (i) the need of a gradual phasing-in of the reforms; (ii) the extensive use of a public information campaign to generate public support for the shift in taxation from goods to environmental evils; (iii) the use of environmental taxes to reduce the revenue taken from other taxes, such as those on income and labour; (iv) the extension of GTR from energy taxes to instruments that give an economic incentive and serve as a filter to undertake energy-saving measures at least cost; (v) the integration of GTR into a much broader fiscal policy package for overhauling the fiscal system and not be perceived as an individual and autonomous fiscal program; (vi) the significance of green tax commissions for implementing GTR, particularly because of their value for improving understanding of concepts and processes; (vi) the use of rebates and exemptions only in a temporary way so that the transition to a more sustainable development is delayed rather than avoided.

Table 2 - Main characteristics of ETRs in European Countries

Country	Year	Reduced or eliminated taxes	Environmental taxes
Sweden	1991	Tax on personal income, employers SSC	Energy tax (CO2) Tax on SO2 emissions Electricity tax Tax on Fertilizers and pesticides, aerial traffic, batteries
Denmark	1993	Tax on personal and corporate income, SSC, capital tax	Adjustment on energy taxes Energy tax (CO2) Tax on SO2 emissions Electricity tax Waste tax
Netherland	1996	Tax on personal and corporate income, SSC	Energy tax (CO2) Tax on SO2 emissions Tax on Fertilizers and pesticides
Germany	1999	SSC	Electricity tax Rise on oil, diesel, heating and natural gas taxes
Norway	1992	Income tax	Energy tax (CO2) Tax on SO2 emissions Tax on Fertilizers and pesticides
Finland	1989 1998	Personal Income tax SSC	Energy tax (CO2) Landfill tax Electricity tax
Italy	1999	SSC	Adjustment on energy taxes Tax on coal and other fuels used in incinerators
Estonia	2005	Income tax	Tax on emissions Tax on natural resources Tax on fuels for transportation It was introduced a tax on natural gas and electricity
Czech Republic	2008	SSC	Energy taxes New tax on CO2 emissions

Source:(Gago, Labandeira, & Rodríguez, (2001) and own elaboration.

1.3. European Union Emission Trade System: definition and experience

The European Commission has pledged to analyze, measure, and apply European policies to reduce the emissions of GHG. In parallel to environmental taxes applied in some European countries, the European Union Emission Trading System (EU ETS) represents the main EU policy against climate change. The economic activities engaged in this market must have emission of CO2 quotas (or emission licences), without which they will not have license to operate. The holders of emission licenses can produce CO2 emissions in an amount equivalent to the received licenses. The installations are, in this way, stimulated to invest in the reduction of emissions and can sell the exceeding licenses in the ECM. The installations that pollute more than the owned licenses will have to buy additional licenses.

The EU ETS was established to that effect by Directive 2003/87/CE and appeared in January of 2005. It is based on six fundamental principles: 1) it is a “cap-and-trade” system (an overall cap is set, defining the maximum amount of emissions, and sources can buy or sell allowances on the open market at European level); 2) its initial focus is on CO2 from big industrial emitters; 3) implementation is taking place in two phases (2005-2007 and 2008-2012) with periodic reviews; 4) emission allowances are decided within national allocation plans; 5) it includes a strong compliance framework; 6) the market is EU-wide but taps emission reduction opportunities in the rest of the world through the use of the Clean Development Mechanism and Joint Implementation, and it also provides for links with compatible systems in third countries (European Commission, 2007b).

The installations covered by the EU ETS initially received allowances for free from each EU Member States government, in what is known as “grandfathering”. However, since unused permits[13] can be sold, installations are stimulated to invest in emissions reduction even when they are under the “cap” (the grandfathered allocated permits). Thus the EU ETS also provides dynamic efficiency.

[13] Carbon permits in the EU ETS are named European Union Allowances (EUA) and each covers one ton of carbon. Henceforth in the thesis we will use the word “permit” when referring to EUA.

Until now, each Member State was able to decide the sum of permits to attribute to the installations regulated by the Directive, following criteria provided by the European Commission. In the two initial phases, a limited number of sectors was included: energy activities (combustion, refineries, coke ovens); iron and steel (production and processing); mineral industries (cement, glass, ceramic products); and pulp and paper. It should be noted that the emissions of the installations covered by the market represent approximately 40% of the total CO2 EU emissions[14] (51% in the Portuguese case for 2006[15]).

In January 2008, the European Commission proposed a number of changes to the scheme, namely: (1) a centralized allocation by a EU authority; (2) a greater share (up to 60 %) of auctioned permits[16]; (3) inclusion of other GHG, such as nitrous oxide and perfluorocarbons (European Commission, 2008); (4) an overall reduction in the proposed caps of GHG in order to reach a 21% decrease in 2020 compared to 2005 emissions[17], and finally (5) a possible extension of the EU ETS to other industries (such as airlines, (European Commission, 2007). These changes are still being discussed, and if approved will only become effective from January 2013 onwards, i.e. in the 3rd trading period of the EU ETS.

In spite of the desirable theoretical properties of emissions permit schemes, it is well known that the nature of the EU ETS raises a few efficiency and fairness concerns (see for example Labandeira and Rodríguez (2010)). Cost-effectiveness of any environmental regulation requires a full coverage of emitters when non-subject sectors present lower abatement costs. Also, any unequal treatment of sectors generates distributional consequences. In defence of the EU ETS design, a market limited to main emitters is appealing due to a reduction of administrative and compliance costs. Furthermore, there is no evidence of market power, which would diminish trading efficiency (Convery & Redmond, 2007).

[14] (European Commission, 2008)

[15] See APA (Agência Portuguesa do Ambiente, 2008) for total CO_2 emissions and NAP summary table for regulated CO_2 emissions

[16] Governments could auction up to 5% of allowances in phase I and up to 10% in phase II. In phase I, only four out of 25 Member States used auctions at all, and in only one case were auctions fully employed to the 5% limit (see Hepburn, Grubb, Neuhoff, Matthes, & Tse (2006) and Ellerman & Buchner (2007).

[17] And 30% compared to 1990 emissions (see European Commission (2007a)).

It is true that a system of emissions trading may be unsuitable for the non-covered sectors. However, this does not wholly justify the differentiated treatment, because other economic instruments could be applicable to these diffuse sectors in order to internalize CO_2 emission costs, like, for instance, environmental taxes.

Bohringer et al (2006) observe the inefficiencies that can occur with EU-ETS by separating the market between trading and nontrading sectors, because it does not allow an equalized abatement cost between all sectors. Furthermore, a hybrid policy that concerns EU ETS plus an environmental tax for the non covered sectors, in a GTR context, would be a good bet as, in this way, we make all CO2 emitters responsible and minimize the cost of the reform. About this, Gimenez and Rodriguez (2010) say that "the EU Emission Trading Scheme could (...) be complemented with other mechanisms such as ETR (environmental tax reform) through a hybrid regulation system, allowing for a wide coverage of polluters with reasonable administrative and compliance costs".

OECD (2002) presents potential motivations for the introduction of taxes in the presence of tradable permits. First, because it is possible to reduce compliance cost uncertainty. In an emissions allowance systems, there is uncertainty about the emission price, because it is determined by the market. So, it is possible to delimit the upper and lower bounds of the permit price, through environmental taxes and subsidies. Mixing the policies, it is possible to reduce the potential welfare losses from the regulatory authority either over-estimating or under-estimating marginal abatement costs. The environmental tax can function as a "safety valve", when applied to the same companies that participate in the emission market. That is, if the permit price reaches the tax (upper bound), the companies will prefer to pay the tax, than purchase additional licenses. For the opposite, if the permit price reaches the subsidy (lower bound) the companies will prefer to receive it than to sell additional permits. Thus diminishing uncertainty, authorities are able to convince risk-averse affected firms and households of the desirability of introducing a tradable permit regime.

Second, it is possible to capture windfall rents from grandfathered permit allocation. When firms receive allocations for free, this represents a windfall rent, if the firm reduces emissions below the level of allocated licenses. When applying an environmental tax to these firms, it is possible to recover some of these windfall rents. The tax is paid in all licenses sold or in stock. In the particular case of electricity sector, there are windfall profits in the production through combined cycle and thermoelectric devices, because these firms include the value of allocated licences in their effective production cost. In fact, these licenses are allocated for free, and only represent an opportunity cost. This way, these firms artificially raise their cost and therefore the electricity price they receive in the market. Here, the environmental tax could be used to diminish these windfall profits, representing a real and computable cost.

Bygrave and Ellis (2003), point that a hybrid policy can operate in a complementary way or there can be a policy transition where one policy follows another. For instance, in UK and Denmark, companies are subject to both taxes and trading. Böhringer et al (2008) investigated the potential efficiency losses arising from the imposition of emission taxes on sectors that are covered by the EU ETS, and concluded that unilateral emission taxes on sectors subject to the EU ETS are environmentally ineffective and increase overall compliance cost of the EU ETS.

Complementary policies can be targeted to work in parallel, targeting different entities. This is the case for Norway, where the emissions trading scheme works in parallel with the carbon tax: the trading scheme includes emissions sources that are exempt from the tax. Also in Ireland, a carbon tax for sectors not covered by the EU ETS was approved. The CO2 tax is applied to transport fuels (Petrol, diesel and coal) and to non-transport fuels (kerosene, marketed gas oil, fuel oil, LPG and natural gas). There are no exemptions except for ETS sectors (Green Budget Europe, 2010a).

Germany also showed a good experience mixing a GTR with EUETS. Environmental taxes like taxes on sulphur, pesticides or water pollution, are effective instruments for dealing with special environmental problems, like acid rain or poor land use, and influence behavior of households and traffic. On the other side, industrial and energy sectors were excluded from GTR and included in EUETS (much more cost-effective and practicable in these sectors). Green Budget Germany (2006) shows some conclusions on combinations of taxes and tradable permit systems. It is pointed in this report that there is a theoretical overlap between environmental taxes and emission trading, because non trading sectors are also indirectly affected in the form of higher energy prices. But, in practice, there is not a greater burden on industrial energy users: "First, industrial businesses in Germany, for example, are only liable to pay the Ecotax at a greatly reduced rate, while the energy sector is only liable to pay it in isolated cases, if at all. Second, the impact of one instrument can be cushioned by the impact of the other: businesses affected by both instruments can profit from the emissions reductions they achieve in response to ETR incentives, by selling the emissions allowances they generate as a result." The main conclusion is that there is a great complementarity between the two instruments, and to give incentives for as many sectors as possible both instruments should be implemented, as few sectors are affected by both.

Portugal, due to the Burden Sharing Agreement, must report, in the period of 2008-2012, a sum of emissions that cannot exceed 27% of the registered emissions in 1990. On one side, Portuguese installations are involved in ECM but, on the other side, Portuguese environmental taxes are still very incipient. Both environmental taxes and ECM are current and pressing policies that urge evaluate. All this motivated us to make and use a model to preview the economic effects of such policies in the Portuguese economy. In this study we do not evaluate the two policies simultaneously, although we intend to do it in a future work.

1.4. Thesis Structure

Environmental taxes in Portugal are a very incipient instrument, so it is important to forecast the economic and environmental effects of raising or introducing such taxes. As GTR was not introduced in Portugal we must use a model to forecast the economic effects of such reform. In respect to EU-ETS, as it is already functioning, we can analyze the present effects and what future consequences it will have in our economy. Such analysis can be made at national level, but it's important also to do it at a regional and sector levels.

By doing such analysis, this thesis reinforce and clarify theoretical concepts like environmental taxes efficiency, GTRs, emission trade systems and, on the other side, gives information for policy making. This study represents a novelty, as there is few literature about these issues for the Portuguese economy[18]. Our study analyzes empirically, through a GEM, the environmental and economic effects of environmental policies.

This doctoral thesis is divided in seven chapters, including this introduction.

First we present a brief survey of recent computational GEM applied to environmental policies. To evaluate the economic impact of environmental and energy policies, namely on employment, a great variety of studies has appeared, from local sector policies concerning waste, water and atmospheric pollution, to global phenomena such as the greenhouse effect. But most of the models used for evaluating climate change policies are GEM, as they provide a consistent framework for studying price-dependent interactions between the energy system and the rest of the economy. In the second chapter we describe what a GEM is and emphasize its importance compared to other economic modelling methods. We also present an abstract of some important works that used GEM applied to energy and environmental policies, referring to some details in modelling, to extensions to basic models and to the integration of GEM with technological and with microeconomic models. We also refer to some simulated policies and its results.

In chapter three the static GEM that we will use in our study is described. In empirical literature we can find diverse applications of static GEM that simulate environmental policies. Of these we emphasize the works of Böhringer, next to other authors, like Rodriguez, whom we will use as the basic references for the construction of our model.

In chapter four, the Social and Environmental Accounting Matrix of Portuguese Economy for the year of 1999, that we constructed to calibrate the previous model, is presented.

Chapter five contains a study about the effects of a GTR in Portugal using the described GEM. In chapter six, we present a study that analyses effects of EU-ETS in Portugal, in a sector and regional level. Finally in

[18] We only know the work of Pereira and Pereira (2011) that we will point in chapters two and three.

chapter seven, we present the main conclusions of this thesis as well as future perspectives of work.

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2. Applied General Equilibrium Models for Energy and Environmental Studies – Some remarks

2.1. Introduction

The importance of energy in any economy, developed or underdeveloped, became clear after the first oil shock in 1973. Those oil shocks questioned the belief that, at a world-wide level, abundant sources of energy existed and would not be an impediment or a brake to the economic growth. The world took conscience that energy is a critical element in contemporary economies. The industrialized countries started to look for a less oil-dependent growth, and since then, different studies have been made to formulate energy policies and to study their impact in the economies.

Given that environmental policies are related with many aspects of the economy, such as price formation, product determination, income generation and distribution, consumption, government behaviour, and others, a systematic and coherent mechanism for such analysis is necessary.

More recently, practitioners of economic and energy models were also concerned with the lack of interaction with natural resources (beyond energy resources), the environment and the climate. Complex models appeared concerning environmental issues, from waste, water and local atmospheric pollution, to regional and global phenomena such as acid rain, the ozone depletion and climate change.

Climate changes seem to be provoked by energy-related activities such as fossil fuel consumption. The risk of climate change makes designing economic development strategies, with proper energy and environmental policies, increasingly important.

Most of the models used for evaluating climate change policies are computational GEM. This chapter makes some comments about the literature on such GEM as applied to environmental and energy studies, and reports their special features.

The first GEM was built by Johansen (1960), but it was in the 90's that this methodology begun to be broadly used (see for instance Conrad (1999) for a survey).

GEM can be described as being "economy-wide", in that they deal with all markets in the economy. Applied GEM assume equilibrium between supply and demand in all markets. The equations in these models also assume optimising behaviour: consumers maximise their utility, producers maximise their profits. In general, markets operate in perfect competition, with equilibrium prices balancing supply and demand. These models are usually calibrated rather than estimated econometrically. This means that substitution elasticities of production or utility functions are taken from other studies, while the parameters are adjusted to describe equilibrium at some benchmark point. Thus, broadly speaking, a GEM works by simulating the interaction of various economic agents across markets subject to behavioural and institutional constraints.

GEM have the capability to capture the complexities of the economy, since economic variables are mutually interdependent. The microeconomic representation of direct effects, as well as indirect feedbacks and spillovers induced by exogenous policy changes, provides a consistent framework for studying price-dependent interactions between the energy system and the rest of the economy. But the advantages of this kind of models can be perceived more obviously when contrasted with other models.

For instance, Technological Models analyze the technology of energy consumers and producers, aiming to determine the net present value of each technology of production that lead to lesser pollution and consumption of energy. This requires a detailed data base about energy demand and supply (see Grubb et al (1993) or Jaccard and Montgomery (1996) for a survey). Alternatively, these models may represent agents' behaviour with the goal of determining the conditions for an optimal management of energy sectors (see Gusbin and Kouvaritakis (2000) or Capros and Mantzos (2000)).

We can also find Economic Models, such us Microeconomic and Macroeconometric Models, of which we can refer as Partial Equilibrium Models. Like the Technological Models, partial equilibrium analysis represents an incomplete representation of the economy (usually one or a limited number of sectors and/or institutions).[19] A partial equilibrium approach is inappropriate to measure "feedback" effects from a particular policy change. It is based on many ceteris paribus assumptions and cannot fully capture all the interactions. By contrast, in a GEM, as the demand for and supply of each commodity depend on all relative prices, the interactions are clearly modelled (Bandara, 1991).

Macroeconometric models, as their name says, are estimated econometrically and therefore rely profoundly on historical data. They usually pay little attention to microeconomic theory, except in broadly deciding which variables to include in the equations of the model. Typically they do not consider balanced markets in the short or medium run, allowing for fluctuations on employment, production capacity, etc. These models were criticized by Lucas (1976) in its role of simulating public policies, since they are based on historical data. Although they are also good in predicting short run effects, GEM can be more appropriate than econometric models to analyse very long-term impacts of changes in policy.[20] But on the other side, GEM have less detail, more aggregation and consequently, are more susceptible of errors and uncertainty.

This chapter does not intend to be a survey about GEM that simulate environmental or energy policies. Our objective is only to introduce this type of models to allow for a better understanding of the study that we are going to present in the next chapters. That study includes simulations of environmental policies through a GEM for the Portuguese economy (like environmental taxes and environmental tax reforms).

So, this chapter is organized as follows. Firstly, we present dynamic and static models, as the main categories of GEM. Secondly, we comment the literature about environmental GEM and describe some details in the design of GEM applied to environmental and energy issues. Then, we present some extensions to basic models and some integrated models, and summarize simulated environmental policies and its results. And finally, we highlight the main conclusions.

[19] See for instance Alfsen et al (1995) or Labandeira and Labeaga (1999) for some applications of partial equilibrium models to environmental policies.
[20] See for instance Barker and Köhler (1998) or Beaumais and Bréchet (1995) for some applications of macroeconometric models to environmental policies.

2.2 Computational General Equilibrium Models categories

It is not easy to classify GEM models. Several criteria can be used to classify them. We will refer only to dynamic and nondynamic (or static) models[21].

GEM dynamic models allow the analysis of the evolution of the economy through time, showing the economic effects of a GTR in the short, medium and long run. The objective is to maximize a social welfare function, subject to dynamic equations of capital stocks and other stock variables. These models typically simulate a forward-looking behaviour of households and firms. The evolution of the economy is usually synthesized by the trajectory of five variables: private capital, public capital, human capital, foreign financing and public debt.

As a result, these models constitute a very complete methodology that demands a high level of information and complexity. For this reason, the main characteristic of the dynamic models "vis-à-vis" static models is that, usually, they consider a lesser degree of disaggregation (a representative consumer, few economic sectors) in order to reduce the complexity of the model[22].

In contrast, static models do not simulate the economic evolution between the initial and the final equilibrium, nor the costs of transition between both. They allow comparing the situation of an ex-ante balanced economy with another ex-post situation after the simulated reform (or shock).

Static models allow for more disaggregation, namely in what concerns the consumer. The representative consumer is frequently replaced by different groups of consumers, each one having its own initial endowment and set of preferences. But it's not a rule (we found dynamic models with more than a representative consumer, as for instance Farmer and Steininger (1999)

[21] Another frequent classification is on single country, multicountry or global models (see Maler and Vincent (2006)). Single country models, have more detailed sectors and households and are used for country specific policies while multicountry or global models have less details on sectors and are used to analyse multilateral policies and transboudary pollution problems.

[22] See for instance Welsh (1996) or Proost and Regemorter (1996) for some aplications of dynamic GEM to environmental policies.

(with 55 different consumers). The disaggregation can be made, for instance, by the number of children (Aasness, Bye and Mysen, 1996), by gender, age, fertility, survival and migration rates (Fisher-Vanden, Shuklac, Edmondsa, Kima, & Pitcher, 1997), by employment status and income levels (Naqvi, 1998; Pench, 2001) and by labour productivity and probability of becoming unemployed (Proost and Van Regemorter, 1995).

2.3 Environmental General Equilibrium Models – some remarks on the literature

In this section, we review some literature about environmental policies, like environmental taxes, and particularly about the Double Dividend hypothesis, modelled through GEM.

Galeotti, Carraro and Bosello (2001) comprises two kind of studies for the Double Dividend hypothesis: one focus on the distortions of the fiscal system before and after the green fiscal reform, looking to the individual welfare and giving little attention to the way the tax revenues are recycled and its consequences for the economy; the other focus on the impact that the recycled tax revenues have on macroeconomic variables (particularly in employment, product or growth). Its main motivation is the reduction of unemployment (therefore this objective is called Employment Double Dividend). A basic hypothesis is that the labour market is in imperfect competition. It is to this second kind of studies that we will pay more attention next, as it fits well in the work that we will present in the next chapter for the Portuguese economy (although our model have perfect competition in labour market).

2.3.1. Details in modelization

Here we summarize some details observed in GEM applied to environmental policies, which differ from GEM with other purposes. We analyze, in particular, the consumer and producer behaviour and some particular extensions to basic models.

We already referred the way the consumer is included on the model. Now we are going to see how studies relate the consumer with the environmental/energy sector. Some include energy as an aggregate consumption good in the utility function (Böhringer and Rutherford, 1997), others make utility depend on environmental quality (Bruvoll and Ibenholt, 1998) and others use more complicated schemes. For instance, Muto, Morisugi and Ueda (2003) present the following scheme:

- households are divided into two types, those who own a private automobile and those who don't;
- the first type of household chooses the traffic mode from the railway, bus, airplane and private automobile;
- the non-owner household decides whether to purchase a private automobile or not;.
- in this decision the household chooses the fuel type from gasoline, diesel and clean energy;.
- if the household is not purchasing a new automobile, it decides to use one of the other traffic modes.

The relation of the production side with the energy/environment sector is also made by several ways. One of them includes a sub model of emissions, which calculates the production of pollutants linked to the use of different types of energy, using specific emission coefficients (Aasness, et al., 1996; C. Böhringer & Rutherford, 1997; Bruvoll & Ibenholt, 1998; X. Labandeira & Rodriguez, 2010; Sahin, 2002). In GEM-E3 (Capros et al., 1996) air pollution affects the number of days that active people are ill, so labour productivity in the production sectors is affected.

In Dellink and Van Ierland (2004), polluters have a choice between paying for their pollution permits and increasing their expenditures on pollution abatement. The abatement sector is modelled as a separate producer that produces 'abatement goods', using both produced goods and primary production factors as inputs. Fisher-Vanden et al. (1997) treated explicitly natural resources, identifying two forms: depletable and renewable. This model was also designed to provide estimates of gaseous emissions from all human activities, including those associated with energy, agriculture, and industrial processes. Emissions are associated with specific human activities and, where appropriate, with specific technologies.

Some models depart from basic models by taking some particular extensions. For instance, the way they include a labour market with involuntary unemployment. This can be made by several ways: simulating unions and wage negotiation (Brunello, 1996; Carraro, Galleotti and Gallo, 1996); including costs of contract and job search (A. Lans Bovenberg & van der Ploeg, 1995) or fixing efficiency and real wages above the equilibrium wage (A. Lans Bovenberg & van der Ploeg, 1993, 1998).

Other models link pollution and consumption, and analyse the redistributive effects of environmental taxes (Smith, 1992; Harrison, 1994). This redistributive issue can be seen in three ways: first, because of the regressive nature of environmental taxes, some empirical studies show that environmental harmful goods are largely consumed by low income persons; second, because the physical incidence of pollution is typically higher in low income groups; and finally, wealthier households attach a higher value to environmental quality.

Other extensions can incorporate technological change, that is, how environmental policies can influence the creation of technology that is new and friendlier to the environment, and how environmental policies interact with innovation policies (L. Goulder & Schneider, 1999; Otto, Løsche, & Reilly, 2006; Popp, 2004).

2.3.2. Integrated models

Another variant of GEM is integrated models that link GEM with partial equilibrium models, like technological or microeconomic models. In this way, these approaches link the advantages of GEM with the advantages of partial equilibrium, particularly adding more detail to some economic agents or sectors.

The incorporation with microeconomic models can be made by three ways. First, by integrating the full version of both models. This option has no loss of precision but makes the model extremely big and algebraically complex, becoming very difficult to apply the model to real data[23].

[23] See for instance Adelman and Robinson (1976)

The second, and more simple, consists in integrating macro details into a microsimulation model, by complementing the micro model with a full-SAM based multiplier analysis, like in Lattarulo et al. (2002), or incorporating an input-output model, as, for instance, in Symons et al. (1994), Labandeira and Labeaga (1999) or Cameron and Ezzeddin (2000). On the other side, micro details can be added to a GEM, expanding the household sphere to include up to as many agents as those existing in family surveys (see for instance Jensen et al., 2002 or Davies, 2004).

Finally (third), micro and GEM can be linked. That could be done in two ways. On one hand, through a sequence in which a static GEM quantifies the effects of policy-induced macroeconomic shocks, and then the microeconometric model takes as exogenous the relative changes in prices and other macro variables which result from the GEM (Bourguignon, Robilliard, & Robinson, 2003; Bussolo & Lay, 2005). On the other hand, through a bi-directional link between the two models, including some restrictions in the models to force a converging solution (see Savard, 2003). For instance, "household behaviour in the GEM could be exogenous (fixed at the benchmark) with the following procedure for simulations: (i) changes in prices and factors from the GEM feed the micro model, which supplies the reaction by each household to macro effects, (ii) the preceding information is used as an input in the GEM, as new values for the households (previously exogenous), and (iii) the GEM is run again and the iterative process continues until convergence is achieved" (in X. Labandeira, Labeaga, & Rodríguez, 2009).

A good example of an article that incorporates a GEM with a microeconomic model, to study the effects of energy taxes, is Labandeira et al. (2009). The authors study the efficiency and distributional effects from changes in Spanish commodity taxation, particularly regarding energy taxes. They use a general equilibrium model, specially designed to simulate energy policies, and a microeconomic household demand system, also with a detailed modelling of energy goods, through a sequential approach, but without bi-directional interactions, by taking the changes in prices and income estimated by the GEM as exogenous values for the household energy demand model. Joining the output (prices) from the GEM to the microeconomic model, it was possible to disaggregate the policy effects on household welfare and to aggregate the results to different groupings of the population. The GEM allowed knowing the policy effects on social welfare, relative prices and levels of activity of different sectors and institutions.

As we said above, there are also models that integrate GEM with technological models. The models can be linked mainly by three ways (C. Böhringer & Rutherford, 2008). First, integrating a reduced form of a bottom-up into a top-down model (Bosetti, Carraro, Galeotti, Massetti & Tavoni, 2006), or vice-versa (Manne, Mendelsohn, & Richels, 2006; Rivers & Jaccard, 2005).

Second, by integrating the full versions of the models[24]. Although this method results in complex models, it has been used, namely for Böhringer and Löschel (2006), to analyze renewable energy policies.

And third, by a soft-link of the models, that allows the communication between the top-down and bottom-up models until they converge. This last method provides the highest degree of detail without forfeiting computational feasibility, but have more inconsistencies in behavioural assumptions and accounting concepts than the previous approaches. Serious problems are certain to be encountered around the convergence of the solution algorithm (C. Böhringer & Rutherford, 2007). Labandeira, Linares, and Rodriguez (2009) follow this methodology and integrate a GEM and an electricity industry model to study the European emissions trading scheme in Spain.

2.3.3 Simulated policies and results

There are a relevant number of studies that use GEM to simulate environmental and energy policies. The first ones appeared in the middle of the 70's, and were concerned with energy supply in the aftermath of the oil shocks of 1973 and 1979. Hudson and Jorgenson (1975) and Manne (1977) were some of these earlier studies. The first one, like most of them, used an energy sector model in which the rest of the economy was represented by an exogenously determined rate of energy demand growth. In contrast, the second one used a detailed energy technology assessment

24 See Böhringer and Rutherford (2008) to a full description of this methodology.

model, which was linked to a neoclassical one-sector model of the rest of the economy.

In the beginning of the 90's, studies turned on issues related with externalities linked with the combustion of fossil fuels in economic activities, that is, mainly CO2 emissions. The GREEN model was developed by the OECD secretariat (Burniaux, Martin & Martins, 1992) to analyze climate change policy issues at a global scale. Simultaneously, other models were developed for single countries, like Hazilla and Kopp (1990). They estimated the social cost of environmental quality regulations using a GEM of the US economy. Whereas Bergman (1990) analyzed the social cost of phasing out nuclear power in the presence of SO_2, NO_x and CO_2 emission constraints, using a GEM of the Swedish economy.

Some models tested the implementation of a carbon tax (Aasness, et al., 1996; S. Bach, M. et al., 2002; C. Böhringer & Rutherford, 1997). In particular, Muto, Morisugi and Ueda (2003) modelled a carbon tax on automobile fuels, which was in part appropriated by a subsidy to the purchase of clean energy vehicles.

Morris et al. (1999) represented scenarios centred on the introduction of environmental load fees on emissions of SO_2, NO_x and particulates, and emission abatement requirements for these pollutants. On the contrary, Naqvi (1998) tested the short-term result of removing import tax on high-speed diesel in Pakistan.

Other models focus on the implementation of energy taxes (see for instance Pench (2001), Sahin (2002) and Bovenberg and Goulder (1997).

In the recent years, another popular simulated policy was a tradable permits system (Dellink & Van Ierland, 2004; Farmer & Steininger, 1999; Iorwerth & al, 2000; X. Labandeira & Rodriguez, 2010; Nwaobi, 2004). For instance, in Sahin (2002) total emissions are limited and determined differently for each sector in each region. Fisher-Vanden, et al. (1997) modelled two emissions allowance allocation schemes: 1) grandfathered emissions allocation- allowances are allocated based on each country's 1990 carbon emissions; 2) equal per capita emissions allocation- allowances are allocated based on each country's share of global population in the current period. Labandeira and Rodriguez (2010) mainly

focus on the (positive) efficiency and distributional effects of the EU emissions trading system, with the use of a static general equilibrium model for the Spanish economy.
In the context of application of environmental taxes, the simulations frequently assume that the government keeps tax changes revenue-neutral, by recycling revenues of environmental taxes or emissions permits through a reduction in labour or capital taxes, in the SSC or through lump-sum transfers. Revenues can also be used to compensate the adversely affected consumers (Farmer & Steininger, 1999) or to subsidize producers of most affected sectors[25]. That is, some models simulate the application of a GTR or the existence of the double dividend hypothesis. For the Portuguese economy, Pereira and Pereira (2011) simulated the revenue recycling through policies that stimulate demand, namely, value added tax replacement and public consumption financing; employment oriented policies, including personal income tax replacement, firms' social security contribution replacement, and human capital investment financing; and, policies that encourage investment in physical capital, including private capital and wind energy capital investment tax credits and public capital financing. This model includes the traditional tax policies, but also includes tax expenditure, renewable energy and public expenditure policies, and so expands the traditional focus of the literature on the double dividend to the quest for a third dividend that is fiscal sustainability.

Results differ between models that simulate different revenue recycling, and between static and dynamic models.

The majority of the static GEM estimate negative effects of this reform on welfare and on the GDP (see Rodriguez (2002) for an extensive survey). However, if this may show the inexistence of the double dividend, we must point out that 24 of the 37 studies analyzed by Rodriguez (2002) considered the devolution of environmental tax revenues through “lump-sum” transfers. This assumption does not optimize the second dividend. It is important, on the other hand, to notice that 40% of the simulations that reduced the labour costs, 67% of the simulations that reduced VAT and 100% of the simulations that reduced the personal income tax or the

[25] in Hill (1998) the revenues are used to give labour subsidies to the “steel and metal sector”, in order to limit negative employment impacts.

public deficit (not neutral reforms), had non negative results on the second dividend.

We can refer for instance the study of Hakonsen & Mathiesen (1997), that includes, in a model applied to Norway, some externalities provoked by air pollution and the traffic of vehicles (costs for the health, materials, productivity). From this work the authors infer that the optimum tax policy without externalities would consist of reducing the CO2 emissions in 10%. When externalities are included in the model, as congestion or public expenses provoked by traffic accidents, the optimum environmental policy would be to reduce CO2 emissions in 15%, through the introduction of a tax of 80US$ for ton of CO2.

Regarding dynamic general equilibrium models, the results obtained in 69 simulations analyzed by Rodríguez (2002) reveal a different panorama concerning the variable that is used to measure the effect of the reform. 90% of the simulations consider that its effect on the job level will be positive or null, whereas only 49% of simulations estimate positive or null effects on the Gross Domestic Product (GDP) and 19% estimate a non negative effect on welfare. Using a dynamic model, Pereira and Pereira (2011) conclude that it is possible to achieve the emission goals while at the same time promoting economic performance and fiscal consolidation.

These results represent, without a doubt, an important support to the double dividend hypothesis and, mainly, to the employment double dividend. This idea is further strengthened if we consider that the welfare measures habitually used do not consider the positive effect provoked by the first dividend, that is, the environmental improvements[26]. We can refer Jorgenson and Wilcoxen (1993), Bye (1996) and Carraro et al (1996) as examples. Jorgenson and Wilcoxen (1993) found that a strong double dividend exists when the revenues from the environmental tax are used to reduce capital taxes. If the revenues were used instead to reduce labour taxes, there would be no strong double dividend. However, neither Goulder (1995) nor Bovenberg and Goulder

[26] The welfare consequences of policy simulations can be measured in several ways. A large number of models use the concept of equivalent variation (EV). The EV can be defined as a percentage of benchmark income and could be interpreted as the amount the household would be willing to pay for the policy to take place. Aasness, Bye, and Mysen (1996) use "money metric utility" and define it as the cost of obtaining a particular utility level at the prices of their base year. Other authors use domestic production, real consumption, private investment, export and import, labour demand and supply and the level of emissions, to measure the policy effects.

(1997), who also used dynamic models of the U.S. economy, found evidence of a strong double dividend. One reason for this may be that both Goulder and Bovenberg & Goulder assumed that capital was immobile across sectors, while Jorgenson and Wilcoxen assumed full inter-sector capital mobility.

In contrast to the results by Jorgenson and Wilcoxen (1993), Bye (2000), who used a dynamic model of the Norwegian economy, found that a revenue-neutral swap, between an increased environmental tax and a reduced tax on labour income, was welfare increasing. According to Bye, the differences between Jorgenson´s and Wilcoxens´s results and her own results depend on the fact that the marginal excess burden is higher for capital taxation than for labour taxation in the U.S., while the opposite holds in Norway. However, in Böhringer and Pahlke (1997), who also used a dynamic model, no strong double dividend could be found.

In static or dynamic models, results can be very different due to the way the recycling of environmental tax is made and to some details in modelization, as we saw in the examples referred above. Following the survey of Rodriguez (2002), we can summarize some conclusions of his study.

The reduction of the SSC paid by the companies is the recycling way most used in the analyzed simulations. 98% and 87% of these simulations estimated positive or null effects in employment and GDP (respectively). Approximately 50% of the simulations consider that its effect on welfare would be non negative. As we said above, since welfare measures commonly used do not consider the positive effect provoked by the first dividend, we can conclude that the effect on welfare is positive in most studies. A GTR that recycles revenues reducing SSC gives a high probability of obtaining a double dividend, and in particular an employment double dividend[27].

The GTRs that recycle environmental taxes through "lump-sum" transfers are the second most used in simulations. In this case, 96% and 85% of the simulations consider that the effects of this kind of reform are negative for the GDP and welfare, respectively. 80% estimate positive or null

[27] Also in an extensive survey Bye and Fæhn (2009) conclude that redistribute tax revenues diminishing the labour tax generates a welfare gain relatively to the unilateral application of the tax.

effects on employment. So, this kind of reform will provoke a smaller economic growth.

The empirical evidence dissuades GTRs that reduce private income tax, due to its negative effect on GDP (82% of the simulations show this). But, on the other hand, 57% of simulations estimate positive or null effect on employment.

Finally, there are few simulations that recycle revenues of the environmental tax through the reduction of the companies' income tax or the value added tax. The results are not very conclusive. We can observe that of the 9 simulations reviewed in which a reduction of VAT was considered, only 1 measure the effect on employment and only 3 measure the effect on welfare.

Bye and Fæhn (2009) also present some conclusions of the empiric work on this issue. They survey two decades of analyses of carbon policies for the small, open economy of Norway. They refer that it is better to welfare if the environmental policy is international instead of unilateral, if the domestic carbon policy apply a uniform price on all carbon emissions, if the redistribution of the carbon tax revenue is made by reducing other distortionary taxes, such as labour taxes, and if there is a differentiated carbon tax system instead of grandfathered tradable emission permits. The introduction of the EU-ETS reduced the public net revenues and the possibility to reach the double dividend through carbon policies. The welfare costs of carbon policies are reduced when it is possible to adopt new technologies, since they are driven by restrictive carbon policies.

Cooperation between countries increases the probability of achieving the employment double dividend, while tax harmonization, without having cooperation in the revenue recycling, cannot reach that goal (Bosello, Carraro, & Fasullo, 1998; Carraro & Galleoti, 1997).

2.4 Conclusions

The objective of this chapter was to introduce GEM applied to the evaluation and prediction of energy and environmental policies, for a better understanding of the study that we are going to present in the next chapters, which includes simulations of environmental policies through a GEM for the Portuguese economy (like environmental taxes, environmental tax reforms or emission trading schemes).

In comparison to other methodologies, GEM appear as the most adequate to simulate energy and environmental policies, since they simulate the interaction of various economic agents across markets subject to behavioural and institutional constraints. These models deal with all markets in the economy, interacting among one another. But there are also some experiences that use GEM linked with technological or microeconomic models, enjoying the advantages of this other kind of models and making the approach more complete.

Dynamic and nondynamic models appear as the main categories of GEM. Both have been used to evaluate environmental and energy policies, but they have important differences in modelization and in its results. Dynamic models are more aggregated, demand a high level of information and are more complex. On the other hand, they analyse the evolution of the economy throughout time, showing the economic effects of a GTR in the short, medium and long run. Static models only compare the situation of an ex-ante balanced economy with different ex-post equilibrium, obtained after the application of the policy. But they are more simple models and allow for more disaggregation.

The way authors relate consumers with environment involves including energy as a consumption good and/or including environmental quality in the utility function. The production sectors are modelled with pollutant emissions linked to the use of different sources of energy or to specific technologies. Pollution can also be included in production, affecting labour productivity.

Extensions to basic models include labour markets with involuntary unemployment, the redistributive effects of environmental taxes analysis, the incorporation of technological change and the integration of GEM with technological or microeconomic models.

The simulated policies in these kind of models are the application of carbon/energy taxes, the simulation of a tradable emission permits system and the test of the Double Dividend hypothesis. As we said before, these are the policies that we are going to simulate for the Portuguese economy in the next chapters.

In what concerns the Double Dividend hypothesis, static models results are more restrictive, but the more positive results are achieved with models that recycle revenues reducing labour costs, IVA or personal income tax, "vis-à-vis" "lump-sum" transfers. Dynamic models give a bigger and stronger support to the Double Dividend hypothesis, in particular to the employment Double Dividend.

In general, the most used simulations recycle revenues reducing SSC, maybe because this strategy is the one that have more positive results on jobs, GDP and welfare.

There are other details in modelling that increase the probability of positive results for welfare, details that are related with the geographic scope of the policy (national or international), with the tax being uniform or differentiated between sectors or even with the possibility of the introduction of new technologies in the economy.

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3. A General Equilibrium Model applied to the analysis of Environmental Policies

3.1. Introduction

The objective of this chapter is to describe the general equilibrium model used in the thesis. This is a static model and has been constructed to evaluate the effect of environmental policies on a small open economy. For this reason, we put emphasis in the treatment of the energy goods produced and consumed by the different economic agents.

In empirical literature we can find diverse applications of static models that simulate environmental policies. Of these, we emphasize the works of Böhringer (together with other authors), which we will use as the basic reference for the construction of our model. In the particular case of Portugal, we only know the work of Pereira and Pereira (2011) that analyzes the effects of environmental policies through an applied general equilibrium model. Their model is very different from the one presented in this thesis, mainly because it is a dynamic model with two sectors (energy sector and non energy sector), and ours is a static model disaggregated in 31 economic sectors. With our model we can simulate substitution effects between sectors and productive factors, and better capture the changes in energy consumption, labour, goods and services, etc. This represents one of the main contributions of the thesis. Another contribution of this model, comparing with others used in the literature, is the treatment given to the consumption of the diverse energy goods by households. A distinction is made between energy goods for the home and energy goods for private transportation.

Besides this introductory section, in section 2 we present the structure of the model and in section 3 the calibration of the model is described.

3.2 The Model

We used an applied static general equilibrium model[28] that describes a small open economy. Its structure is similar, except for small differences, to the one used in Böhringer, Ferris, & Rutherford, 1997. As we said before, the data base used in the model considers the existence of thirty one productive sectors. We departed from the sixty sectors of the National Accounts, aggregating some of them, because other information available (like fossil fuels consumption) had not the same disaggregation. There are three additional institutional sectors in the economy: the public sector, the foreign sector and the private sector (that includes households, the financial and no financial firms, and the NPISH[29]).

The different taxes used in the model have been programmed ad-valorem, and we have not considered the existence of exchange rates. This decision is a consequence of the monetary union in the UE. Therefore we supposed that the reforms being simulated will have an insignificant impact in international exchange markets and, in particular, in the exchange rate of Euro versus other currencies. This assumption is reasonable considering that most of the foreign commercial relations of Portugal take place with UE countries members of the monetary union. As a general criterion, notation follows the following convention: the endogenous variables are denoted by capital letters, the exogenous variables are denoted by capital letters and a bar, and the parameters of the model are denoted by Greek and Latin letters. There are n productive sectors (i, j=1,…, n) and, consequently, n consumer goods.

For the resolution of the general equilibrium model we used the method proposed by Rutherford (1999). The analytical approach is based on the work of Mathiesen (1985) that solves a general equilibrium model by a mixed complementarity problem[30].

[28] See Shoven and Whalley (1992) for one first approach to applied computational general equilibrium models.

[29] The aggregation of households, firms and NPISH was made to simplify the model and do not reduce the output quality or the information requirements on the issues we want to study in this thesis. We also avoid the controversy around the disaggregation of these institutional sectors, because economic decisions taken by the firms or by the NPISH would have to be in the scope of the households, who are the true owners of these institutions.

[30] For a very brief and clear description of this approach of analysis see Gomez (2002).

3.2.1 Production

The productive sectors use a technology with constant returns, characterized by a succession of nestings in which different intermediate goods and primary factors are combined[31]. In each nesting the producer minimizes its costs, subject to technological restrictions. We suppose that the markets are perfectly competitive and, therefore, the equilibrium profits will have to be null in each productive activity. The solution to the optimization problem will result in a function of unit costs associated to the production of each good that in equilibrium will be equal to the net price received by the producers. The first level, or nesting, will determine the function of unit costs associated to each good. Here we combine a good made up of primary productive factors and energy goods KEL, with different intermediate goods CID (from which electricity, coal, natural gas, and refined products of petroleum, have been excluded). A Leontief technology[32] was used so that the problem can be characterized the following way:

$$\min_{KEL,CID} PB_i.(1-TB_i+SB_i).B_i = PKEL_i.KEL_i + \sum_{j=1}^{n} PD_j.CID_{ji} \quad (1)$$

$$s.t.B_i = \min\left(\frac{KEL_i}{c_{0i}}, \frac{CID_{1i}}{c_{1i}}, \ldots, \frac{CID_{ni}}{c_{ni}}\right) \quad (2)$$

Where the PBi is the market unitary price of output Bi (the gross producer price), TBi is the effective marginal tax on the production, SBi is the marginal subsidy on the production, PKELi is the unitary price of the good KELi, PD is the unitary domestic market price of the intermediate goods CIDi, and c0i, cni are the Leontief coefficients.

Next, we present the solution to this problem; this solution will be applied, in a symmetrical way, to the remaining optimization problems. The resolution of the previous problem of optimization will provide us the cost function of each branch of activity. From the condition of null

[31] The nested functions allow us to specify different elasticities of substitution between the different productive inputs. This characteristic is especially interesting in the case of energy goods. Rutherford and Perroni (1998) describe the specification of Allen-Uzawa elasticities of substitution between different productive factors with non-separable nested functions CES.

[32] It is usual in applied GEM that the producers combine primary productive factors (capital and labour) with intermediate goods by means of a Leontief technology. See for instance Kehoe and others (1989).

benefits (3) we can obtain the demand of each good (4) and (5) applying the Shepard's Lemma,

$$\pi_i^B = PB_i.(1-TB_i+SB_i).B_i - PKEL_i.KEL_i - \sum_{j=1}^{n} PD_j.CID_{ji} = 0 \tag{3}$$

$$KEL_i = -\frac{\partial \pi_i^B}{\partial PKEL_i} B_i \tag{4}$$

$$CID_{ji} = -\frac{\partial \pi_i^B}{\partial PD_i} B_i \tag{5}$$

In the second level, we combine primary productive factors KL_i with the different energy goods E_i. A CES technology is used, so that the problem can be characterized like:

$$\min_{KL,E} PKEL_i.KEL_i = PKL_i.KL_i + PE_i.E_i \tag{6}$$

$$s.t.KEL_i = \alpha_i \left(a_i KL_i^{\frac{\sigma_i^{KEL}-1}{\sigma_i^{KEL}}} + (1-a_i) E_i^{\frac{\sigma_i^{KEL}-1}{\sigma_i^{KEL}}} \right)^{\frac{\sigma_i^{KEL}}{\sigma_i^{KEL}-1}} \tag{7}$$

Where PKL_i is the unitary price of composed good KL_i, PE_i is the unitary price of composed good Ei, α_i is the scale parameter, a_i is the weight of KL_i, and σ_i^{KEL} is the substitution elasticity.

In order to obtain the unit costs associated to the use of primary productive factors KL and to the consumption of energy E, we must solve in the third level (or nesting) the following problems:

$$\min_{K,L} PKL_i.KL_i = PK.K_i + w.(1+CSS\_ACT_i).L_i \tag{8}$$

$$s.t..KL_i = \alpha_{iKL}(a_{iKL} L_i^{\frac{\sigma_i^{KL}-1}{\sigma_i^{KL}}} + (1-a_{iKL}) K_i^{\frac{\sigma_i^{KL}-1}{\sigma_i^{KL}}})^{\frac{\sigma_i^{KL}}{\sigma_i^{KL}-1}} \tag{9}$$

Where PK is the unitary price of the capital K_i, w is the unitary price of labour L_i, CSS_ACT_i is the effective marginal social contributions paid by the employers, α_{iKL} is the scale parameter, a_{iKL} is the weight of labour, and σ_i^{KL} is the substitution elasticity.

$$\min_{ELEC,EP} PE_i.E_i = PELEC.ELEC_{iA} + PEP_i.EP_i \tag{10}$$

$$s.t.E_i = \alpha_{iE}\left(a_{iE}ELEC_{iA}^{\frac{\sigma_i^E-1}{\sigma_i^E}} + (1-a_{iE})EP_i^{\frac{\sigma_i^E-1}{\sigma_i^E}}\right)^{\frac{\sigma_i^E}{\sigma_i^E-1}} \tag{11}$$

Where PEP_i is the unitary price of energy primary goods EP_i, PELEC is the unitary price of electricity $ELEC_{iA}$ consumed by each branch of activity, α_{iE} is the scale parameter, a_{iE} is the weight of electricity in energy consumption, and σ_i^E is the substitution elasticity.

In the fourth level, the coal consumption $COAL_A$ and hydrocarbons HIDRO are combined by a CES function, so that each activity must solve the following problem:

$$\min_{COAL,HIDRO} PEP_i.EP_i = PCOAL.COAL_{iA} + PHIDRO_i.HIDRO \tag{12}$$

$$s.t.EP_i = \alpha_{iEP}\left(a_{iEP}COAL_{iA}^{\frac{\sigma_i^{EP}-1}{\sigma_i^{EP}}} + (1-a_{iEP})HIDRO_i^{\frac{\sigma_i^{EP}-1}{\sigma_i^{EP}}}\right)^{\frac{\sigma_i^{EP}}{\sigma_i^{EP}-1}} \tag{13}$$

Where PCOAL is the unitary price of coal $COAL_{iA}$, $PHIDRO_i$ is the unitary price of hydrocarbons $HIDRO_i$, α_{iEP} is the scale parameter, a_{iEP} is the weight of coal in EP, and σ_i^{EP} is the substitution elasticity.

Finally, in the fifth level the unit costs are determined to be associated to the hydrocarbon consumption. By means of a CES function we obtain the optimal combination of petroleum refined products REF_{iA} and natural gas GAS_{iA} consumed by each branch of activity.

$$\min_{REF,GAS} PHIDRO_i HIDRO_i = PREF.REF_{iA} + PGAS.GAS_{iA} \tag{14}$$

$$s.t.HIDRO_i = \alpha_{iPET}\left(a_{iPET}REF_{iA}^{\frac{\sigma_i^{PET}-1}{\sigma_i^{PET}}} + (1-a_{iPET})GAS_i^{\frac{\sigma_i^{PET}-1}{\sigma_i^{PET}}}\right)^{\frac{\sigma_i^{PET}}{\sigma_i^{PET}-1}} \tag{15}$$

Where PREF is the unitary price of petroleum refined products REF_{iA}, PGAS is the unitary price of gas GAS_{iA}, α_{iPET} is the scale parameter, a_{iPET} is the weight of REF, and σ_i^{PET} is the substitution elasticity.

The total supply of goods in the economy is a good A_i composed by the national production B_i and imported goods IMP_i, assuming, as it is usual in these models[33], that the goods of different origin are imperfect substitute products. Using a CES technology, each branch of activity determines the optimal combination of national and imported goods that minimizes the price of products supplied in the economy. Therefore, the problem which each branch of activity faces is the following,

$$\min_{B,IMP} PA_i.A_i = PB_i.B + \overline{PXM}_i.IMP_i \tag{16}$$

$$s.t. A_i = \lambda_i \left(b_i B_i^{\frac{\sigma_i^A - 1}{\sigma_i^A}} + (1-b_i) IMP_i^{\frac{\sigma_i^A - 1}{\sigma_i^A}} \right)^{\frac{\sigma_i^A}{\sigma_i^A - 1}} \tag{17}$$

Where PA_i is the unit cost of the Armington good A_i, PXM_i is international unitary price of imported goods IMP_i (considered exogenous), λ_i is the scale parameter, b_i is the weight of the national production, and σ_i^A is the substitution elasticity.

The final destination of supplied goods in the economy A_i is: exports EXP_i or domestic consumption D_i. Using a transformation function CET[34], each branch of activity determines the optimal product combination supplied in the domestic or international markets that maximize their income, subject to the restriction of null profits. Therefore, the problem which each branch of activity faces is the following:

33 See Shoven and Whalley (1992)

34 CET functions allow certain degree of substitution between different goods that have different markets. For a brief description see Shoven and Whalley (1992).

$$\max_{D,EXP} PA_i.A_i = PD_i.(1 - TD_i + SD_i - TE_i).D_i + \overline{PXM}_i.EXP_i \quad (18)$$

$$s.t.A_i = \gamma_i \left(d_i D_i^{\frac{\sigma_i^{\varepsilon}+1}{\sigma_i^{\varepsilon}}} + (1-d_i) EXP_i^{\frac{\sigma_i^{\varepsilon}+1}{\sigma_i^{\varepsilon}}} \right)^{\frac{\sigma_i^{\varepsilon}}{\sigma_i^{\varepsilon}+1}} \quad (19)$$

Where PD_i is the unitary sale price to the public of good Di in the domestic market, TD_i is the effective marginal tax on products, SD_i is the effective marginal subsidy to products, TE_i is the marginal environmental tax on products, γ_i is the scale parameter, d_i are the weights, and σ_i^{ε} is the transformation elasticity.

3.2.2. Private Sector

As we said above, this model aggregates the households, the financial and no financial firms, and the NPISH. The financial and nonfinancial firms represent a peculiar type of agents who exert property rights on the diverse productive activities on behalf of other agents, namely the households or the public sector.

They take decisions about the destiny of the property rents (to distribute dividends, for example). In addition, they receive and make diverse transfers in favor of different agents, and pay a tax on the rents of the firms. Similarly, the NPISH could be interpreted as a particular kind of institution, halfway between firms and the public sector. They also exert property rights on diverse productive activities in representation of other agents, although they do not pay any tax on the generated rents. In addition, they receive and make diverse transfers to different agents.

We assume the consumer has a fixed endowment of capital and labour. The labour endowment represents the maximum time endowment that the consumer can dedicate to work (the maximum labour supply), and is equal to the sum of time dedicated to leisure and to work, in the equilibrium. The problem of the consumer is to maximize his utility, subject to a budgetary restriction. The decisions of the representative consumer have been modelled by means of nested CES functions.

In the first nesting the consumer decides the optimal combination between leisure (LEISURE) and a good made up of saving, goods and services (UA). This combination is determined by means of a CES function, as described below:

$$\max_{LEISURE,UA} W = \left(s_{UB} LEISURE^{\frac{\sigma^{UB}-1}{\sigma^{UB}}} + (1-s_{UB}) UA^{\frac{\sigma^{UB}-1}{\sigma^{UB}}} \right)^{\frac{\sigma^{UB}}{\sigma^{UB}-1}} \quad (20)$$

$$s.t. Y_{CONS} = \sum_{i=1}^{n} PD_i . D_{iH} + PSAV . SAV_{CONS} + w.(1 - CSS\_HOU).LEISURE \quad (21)$$

Where Y_{CONS} is the available yield of the representative consumer, PSAV is the price of saving, SAV_{CONS} is the saving, CSS_HOU is the effective marginal social contributions in charge of the employees, s_{UB} is the weight of leisure, and σ^{UB} is the substitution elasticity.

In the second nesting the consumer decides the optimal combination between saving SAVCONS and a good made up of different goods and services FCHOU, minimizing the expense in both goods. We will suppose, like in Böhringer and Rutherford (1997), that the consumers have a constant marginal propensity to save on the set of their available yield, which seems reasonable being a static model. For it, we used a Leontief function so that the problem is the following:

$$\min_{SAV,FCHOU} PUA.UA = PSAV . SAV_{CONS} + PFCH . FCHOU \quad (22)$$

$$s.t. UA = \min\left(\frac{SAV_{CONS}}{s_{UA}}, \frac{FCHOU}{(1-s_{UA})} \right) \quad (23)$$

Where PUA is the unitary price of composed good UA formed by saving and the final consumption of goods and services FCHOU, s_{UA} is the weight of saving in composed good UA.

The main contribution of this model, versus others in the literature, is the treatment given to the consumption of the diverse energy goods by households. We distinguished between energy goods for the home and energy goods for private transportation.

The energy goods for the home[35] provide to their members a set of services, like heat (of a heating system), refrigeration, artificial light, cooked food, washing of clothes and dishes, etc. Under energy goods for the home we grouped electricity, coal, natural gas, and refined products of petroleum, like heating oil and LPG.

As a result of the previous nestings, the consumer decides in the third nesting the optimal combination between energy for home (EHOU), refined products of petroleum for private transport[36] (FUELOIL), and a good made up of the remaining goods and services (OTHERS), by means of a CES function:

$$\min_{EHOU,FUELOIL,OTHERS} PFCH.FCHOU \tag{24}$$

$$s.t.$$

$$FCHOU = \varphi_{FCH}\left(s_E EHOU^{\frac{\sigma^{FCH}-1}{\sigma^{FCH}}} + s_F FUELOIL^{\frac{\sigma^{FCH}-1}{\sigma^{FCH}}} + (1 - s_{EH} - s_{RH})OTHERS^{\frac{\sigma^{FCH}-1}{\sigma^{FCH}}} \right)^{\frac{\sigma^{FCH}}{\sigma^{FCH}-1}}$$

$$PFCH.FCHOU = PEH.EHOU + PFUEL.FUELOIL + POTHERS.OTHERS \tag{25}$$

Where PEH is the price of EHOU, PFUEL is the price of FUELOIL, POTHERS is the price of OTHERS, φ_{FCH} is the scale parameter, s_E and s_F are the weights of EHOU and FUELOIL respectively, and σ^{CFH} is the substitution elasticity.

In the fourth nesting, the consumer decides, on the one hand, the optimal combination between electricity (ELECH) and a good made up of other primary energy goods for home (EPHOU) (coal, heating oil, propano and butano) by means of a CES function and, on the other hand, the optimal

[35] The distinction between energy goods for home and other energy goods is usual in microeconometric models that analyze the energy consumption of the households. See for instance Baker, Blundell and Micklewright (1989).

[36] We assumed that 62% of the households consumption of refined products of petroleum were destined to the private transport during the year of 2005. The other 38% were destined to provide energy services for the home, like the production of hot water, food heating, cooking. This assumption is based on the data offered by the Continuous Survey of Familiar Budgets, elaborated by INE for year 2005/2006.

combination between the remaining goods and services D_{iH} by means of a Cobb-Douglas function.

$$\min_{ELEC,EPHOU} PEH.EHOU = PELEC.ELEC_H + PEPH.EPHOU \quad (26)$$

$$\text{s.t. } EHOU_h = \varphi_{EH}\left(s_{EH} ELEC_H^{\frac{\sigma^{EH}-1}{\sigma^{EH}}} + (1-s_{EH}) EPHOU^{\frac{\sigma^{EH}-1}{\sigma^{EH}}} \right)^{\frac{\sigma^{EH}}{\sigma^{EH}-1}} \quad (27)$$

$$\min_D POTHERS.OTHERS = \sum_{i=1}^{n} PD_i.D_{iH} \quad (28)$$

$$s.t. OTHERS = \prod_{i=1}^{n} D_{iH}^{SO_i} \quad (29)$$

Where PEPH is the price of EPHOU, POTHERS are the price of OTHERS, φ_{EH} is the parameter of scale, s_{EH} is the weight of $ELEC_H$ in EHOU, SO_i is the weights of D_{iH} in OTHERS (the weights of energy goods in this function are null), and σ^{EH} is the elasticity of substitution between $ELEC_H$ and EPHOU.

Finally, in the fifth nesting the consumer decides the optimal combination of primary energy goods for the home, excluding electricity.

$$\min_{COAL,GAS,REF} PEPH.EPHOU = PCOA.COAL_H + PGAS.GAS_H + PREF.REF_H \quad (30)$$

$$s.t. EPHOU = \varphi_{NEH}\left(s_C COAL_H^{\frac{\sigma^{NEH}-1}{\sigma^{NEH}}} + s_G GAS_H^{\frac{\sigma^{NEH}-1}{\sigma^{NEH}}} + (1-s_C-s_G) REF_H^{\frac{\sigma^{NEH}-1}{\sigma^{NEH}}} \right)^{\frac{\sigma^{NEH}}{\sigma^{NEH}-1}} \quad (31)$$

Where φ_{NEH} is the scale parameter, s_C and s_G are the weights of $COAL_H$ and GAS_H respectively, and σ^{NEH} is the substitution elasticity. REF_H represents the products derived from petroleum that provide energy for the home.

The available yield of the representative household is,

$$Y_{CONS} = (1-TCONS)\left[PK.\overline{K}_{CONS} + w(1-CSS\_HOU).\overline{TIME} + \overline{TRANSFHOU}\right] - \overline{CR} \quad (32)$$

where TCONS is the effective marginal tax on the rents of the households, K_{CONS} is the capital endowment, CSS_HOU is the effective marginal social quotations in charge of the workers, TIME is the time endowment that the consumer can dedicate to leisure or the work, TRANSFHOU are the net received transfers[37], and CR is the consumption made abroad by the resident households.

3.2.3. Public Sector

The public sector provides diverse goods and services of collective character (health and public education, security, etc), and serves social protection by means of transfers. The public consumption of goods and services is an aggregated good FCGOV, through a Cobb-Douglas function of the diverse products supplied in the economy D_{iG}. The public sector finances this with the income generated by the fiscal system, property rents and transfers. In addition, it has a fixed endowment of capital that also provides income. The problem of the public sector is to maximize the public consumption subject to a budgetary restriction, as it is indicated next:

$$\max_D FCGOV = \prod_{i=1}^{n} D_{iG}^{GOV_i} \qquad (33)$$

$$\begin{aligned} s.t. Y_{GOV} &= PK.\overline{K}_{GOV} + TEMP + RECTCONS + \overline{TRANSFGOV} + \\ &+ PSAV.SAV_{GOV} + PB_i.(TB_i - SB_i).B_i + PD_i.(TD_i - SD_i + TE_i).D_i + \\ &+ w.\left(\sum_{i=1}^{n} CSS\_EMP_i.L_i + CSS\_HOU \sum_{i=1}^{n} L_i \right) \end{aligned} \qquad (34)$$

where GOV_i is the weight of each good in FCGOV, Y_{GOV} is the rent available of the public sector, K_{GOV} is the endowment of capital of the public sector, RECTCONS is the total revenue from the tax on the rent of the representative consumer, TRANSFGOV are the net transfers received[38] by

[37] The net received transfers TRANSFHOU, are the sum of the property rents, wages paid by the rest of the world, social benefits, transfers of other institutions, an adjustment of the national accounting by the variation of the net participation of the households in the reserves of pensions, except the social contributions paid by the households to the financial and nonfinancial firms.

[38] The net received transfers, TRANSFGOV, are the sum of the revenues of the rent tax on the nonresident, the received transfers of the rest of the world, except the net property rents of the public sector, the social contributions paid to the rest of the world, the social benefits paid by the public sector, and other transfers paid by the public sector to other institutions.

the public sector, and SAV_{GOV} is the financing received in form of saving of the remaining institutions.

The taxes are programmed ad-valorem in the general equilibrium model. Nevertheless, the environmental tax that we want to simulate represents an ad-quantum tax (unitary). With the purpose of making both objectives compatible, the tax rate of the environmental ad-valorem tax is an endogenous variable of the model, in such a way that its revenues will be equivalent (identical) to those of the ad-quantum tax. For it, we have used in the model the following restriction

$$TE_i.PD_i.D_i = D_i.AQET_i \tag{35}$$

Where TE_i is the advalorem endogenous environmental tax on the good D_i, and $AQET_i$ is the ad-quantum exogenous environmental tax on good D_i.

3.2.4. Investment and saving

The total investment of the economy INV is a good made up of the gross formation of capital in the different branches of activity, using a Leontief function of fixed coefficients. Therefore, the optimization problem, which the economy is due to face, aims to diminish the unit costs of the total investment,

$$\min_D PINV.INV = \sum_{i=1}^{n} PD_i D_{iINV} \tag{36}$$

$$s.t. INV = \min\left(\frac{D_{iINV}}{v_{iINV}},\dots,\frac{D_{nINV}}{v_{nINV}}\right) \tag{37}$$

Where D_{iINV} is the gross formation of capital in the good D_i, and v_{iINV} are the fixed coefficients.

The national saving is the sum of the saving made by each one of the previous described institutions, and so it has an endogenous character. The macroeconomic equilibrium of the model will be determined by the economy capacity or necessity from financing of the outside CAPNEC, that will be equal to the difference between national saving and investments,

$$PSAV.(SAV_{PRIV} + SAV_{GOV}) - PINV.INV = \overline{CAPNEC} \quad (38)$$

3.2.5. Foreign sector

In this model we have assumed a small open economy, in such a way that prices of the goods and services in the international markets PXM_i are fixed and, therefore, exogenous. This means that the supply of imports and the demand of exports are perfectly elastic. Also the transfers and the net property rents coming from the outside are perceived as exogenous by the different institutions, and so is the consumption made abroad by the resident households.

Finally, we must not forget the final consumption made by the nonresidents (CNR), mainly formed by the tourists' consumption. The amount of goods and services consumed by the nonresidents D_{iRW} will be considered exogenous in our model, due to the impossibility to represent the budgetary restriction which the nonresident consumers face. The equation that describes the balance of payments (40) will determine the macroeconomic balance of this economy versus the outside.

$$CNR = \sum_{i=1}^{n} PD_i.\overline{D}_{iRW} \quad (39)$$

$$\sum_{i=1}^{n} \overline{PXM}_i.EXP_i + \overline{TRANSFRW} + CNR - \sum_{i=1}^{n} \overline{PXM}_i.IMP_i - \overline{CR} = \overline{CAPNEC} \quad (40)$$

Where TRANSFRW are the net transfers received[39] by the rest of the world.

3.2.6. Market of factors

In this economy there are two primary productive factors: capital and labour. The supply of capital is equal to the sum of the fixed endowments of each one of the institutions considered in the model. The supply of capital is inelastic, movable between sectors, but perfectly immovable internationally. The demand of capital by each branch of activity is

[39] The received net transfers, TRANSFRW, are the sum of the social quotations paid to the rest of the world, the property rents paid to the rest of the world, less wages paid by the rest of the world, the rent tax of the nonresidents, social quotations associated to the work made by the households resident in the rest of the world, the transfers made by the UE, and other transfers paid by the rest of the world to other institutions.

determined by the solution to the problem of minimization of costs which each producer faces, as was indicated previously. The remuneration of the capital is an endogenous variable of the model, so that it satisfies the restriction of market clearing. That is to say, equalizing supply and demand of capital:

$$\overline{K}_{PRIV} + \overline{K}_{GOV} = \sum_{i=1}^{n} K_i \qquad (41)$$

The representative consumer is the only supplier of work. As we have indicated previously, the representative consumer has a fixed endowment of time (TIME) that can use to supply labour or to consume in leisure form. Like in Böhringer and Rutherford (1997), we supposed a competitive labour market and, therefore, an economy without involuntary unemployment[40]. The supply of work is movable between sectors, but perfectly immovable internationally. The demand of work made by each branch of activity is determined by the solution to the problem of minimization of costs which each producer faces, as was previously indicated. The remuneration of the work is an endogenous variable of the model, so that it satisfies the restriction of market clearing. That is to say, equalizing supply and demand of labour:

$$\overline{TIME} - LEISURE = \sum_{i=1}^{n} L_i \qquad (42)$$

3.2.7. The environmental model

At the present time, there are no technical processes that allow reducing CO_2 emissions which take place during the fossil fuel combustion. That is to say, there is a relation of proportionality between the physical units consumed of different fossil fuels and the CO_2 emissions to the atmosphere.

The environmental submodel, will simulate the inner CO_2 emissions, i.e., those that are generated by the different domestic branches of activity

[40] In our model, with a household or representative consumer, the amount of work in equilibrium represents the work made by the occupied population, and the leisure consumption in fact represents the leisure consumed by the occupied population, and the leisure (voluntary or not) consumed by the active population but not occupied. Therefore, the possible changes in the supply of work considered by the model represent changes in the supply of work of the active population.

($CO2_i$) and the inner consumption from resident households ($CO2_H$). In order to do this, we calculated an emission coefficient that relates the consumption of each one of the different primary energy goods and the emissions generated during its combustion.

$$CO2_i = CO2C_i.COAL_{iA} + CO2P_i.REF_{iA} + CO2G_i.GAS_{iA} \qquad (43)$$

$$CO2_H = CO2C_H.COAL_H + CO2P_H.(FUELOIL_H + REF_H) + CO2G_H.GAS_H \qquad (44)$$

Where $CO2C_i$ and $CO2C_H$ are the coefficients of emission of the coal consumed by sector i and the representative household, respectively. In a similar way, $CO2P_i$ and $CO2P_H$ are the coefficients of emission of refined products of petroleum, and $CO2G_i$ and $CO2G_H$ are the coefficients of emission of natural gas.

3.3. Calibration of the model

The data that we have used to calibrate the model come from a Social Accounting Matrix (SAM) for the Portuguese economy constructed on purpose for this study, from the national accounting for the year 1999. The steps for the elaboration of the Portuguese SAM for the year 1999 are described in chapter 4. Taking the data contained in the SAM we can calibrate[41] (specify) the necessary parameters of the model so that it is able to reproduce these data like an optimal solution of general equilibrium. Nevertheless, certain fundamental parameters of the model, like the substitution elasticities, have not been calibrated but taken from empirical literature. The elasticities, along with the amounts and prices of reference in the initial equilibrium, characterize the technologies and the preferences of the agents through the calibration of the model.

The data contained in the national accounting and in the SAM represent monetary values, and do not distinguish between prices and amounts. Therefore, it is normal in applied GEMs to follow the convention originally used in Harberger (1962). Following this convention, the units used to measure the different goods and services, and also the factors, have been chosen in such a way that their prices are equal to the unit in

[41] For a brief introduction to this methodology, see Shoven and Whalley (1992).

the initial equilibrium situation. The model of general equilibrium has been programmed with GAMS/MPSGE, and the calibration has been implemented following the method proposed in Rutherford (1999).

The elasticity of the supply of labour has been calibrated following the procedure used in Ballard et al. (1985), in such a way that the model is able to reproduce the uncompensated elasticity of the supply of labour contained in empirical literature. In a model with a representative consumer, the elasticity of the supply of labour must be interpreted as the changes in the effective supply of labour of the economy versus changes in the net real wage (Goulder et al., 1997).

Therefore, it is the result of changes in the participation of the households in the labour market, changes in the duration of the work day, and changes in the effort.

The preferences of the representative household in relation to the different goods and services have been calibrated using the following elasticities of substitution, calculated by Rutherford and Paltsev (2000). The elasticity of substitution between fuels for private transport, energy goods for the home, and a composed good by the remaining goods σ^{CFH} is 0,1. The elasticity of substitution between electricity and the remaining energy goods for the home σ^{EH} is 1,5. The elasticity of substitution between coal, natural gas, and the remaining refined products of petroleum that provide energy for the home σ^{NEH} is 1.

The technology of the different branches of activity was calibrated using the elasticities of substitution that are presented in Table 3. The concerned elasticities of substitution between capital and work σ_i^{KL} in each productive sector, as well as elasticities between national production and imported goods σ_i^{A}, have been taken from GTAP (Hertel, 1997). The elasticities of transformation of the supply between products for exports and products for the domestic markets σ_i^{ε} have been taken from deMelo and Tarr (1992). The substitution elasticities between aggregate E (energy) and aggregate KL (capital and work) in each productive sector σ_i^{KEL} has been taken from Kemfert and Welsch (2000). The elasticity of substitution between electricity and EP (the remaining primary energy goods) σ^{E}, the elasticity of substitution between coal and hydrocarbons σ^{EP}, and the elasticity of substitution between natural gas and ref (the remaining refined products of petroleum) σ^{PET}, have been taken from Boheringer et al. (1997).

Table 3 – Substitution elasticities

	σ_i^{KEL}	σ^{E}	σ_i^{KL}	σ^{EP}	σ^{PET}	σ_i^{A}	σ_i^{ε}
AGRSIL	0,5	0,3	0,56	0,5	0,5	2,2	3,9
PESCA	0,5	0,3	0,56	0,5	0,5	2,2	3,9
EXTENE	0,5	0,3	1,26	0,5	0,5	2,8	2,9
EXTRAC	0,96	0,3	1,26	0,5	0,5	1,9	2,9
ALITAB	0,5	0,3	1,26	0,5	0,5	2,8	2,9
TEXTIL	0,8	0,3	1,26	0,5	0,5	2,8	2,9
COURO	0,8	0,3	1,26	0,5	0,5	2,8	2,9
MADCOR	0,8	0,3	1,26	0,5	0,5	2,8	2,9
PAPIMP	0,8	0,3	1,26	0,5	0,5	2,8	2,9
REFPET	0,5	0,3	1,12	0,5	0,5	2,8	2,9
QUIMIC	0,96	0,3	1,26	0,5	0,5	1,9	2,9
PLAST	0,8	0,3	1,26	0,5	0,5	2,8	2,9
MINER	0,96	0,3	1,26	0,5	0,5	1,9	2,9
METAL	0,8	0,3	1,26	0,5	0,5	2,8	2,9
MAQEQU	0,8	0,3	1,26	0,5	0,5	2,8	2,9
EQUIEL	0,8	0,3	1,26	0,5	0,5	2,8	2,9
MATRANS	0,8	0,3	1,26	0,5	0,5	2,8	2,9
INDTRAN	0,96	0,3	1,26	0,5	0,5	1,9	2,9
ELECT	0,5	0,3	1,26	0,5	0,5	2,8	2,9
GAS	0,5	0,3	1,12	0,5	0,5	2,8	2,9
AGUA	0,5	0,3	1,26	0,5	0,5	2,8	2,9
CONST	0,5	0,3	1,4	0,5	0,5	1,9	0,7
COMER	0,5	0,3	1,68	0,5	0,5	1,9	0,7
RESTA	0,5	0,3	1,68	0,5	0,5	1,9	0,7
TRANSCOM	0,5	0,3	1,68	0,5	0,5	1,9	0,7
FINAN	0,5	0,3	1,68	0,5	0,5	1,9	0,7
IMOBALUG	0,5	0,3	1,68	0,5	0,5	1,9	0,7
ADMPUB	0,5	0,3	1,68	0,5	0,5	1,9	0,7
EDUCA	0,5	0,3	1,68	0,5	0,5	1,9	0,7
SAUDE	0,5	0,3	1,68	0,5	0,5	1,9	0,7
SERVI	0,5	0,3	1,68	0,5	0,5	1,9	0,7
EMPDOM	0,5	0,3	1,68	0,5	0,5	1,9	0,7

Source: own elaboration.

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4. A Social and Environmental Accounting Matrix of the Portuguese Economy for 1999

The data that we have used in the model come from a SAM for the Portuguese economy constructed from the national accounting for the year 1999. In order to elaborate the SAM-1999 we have taken as starting point the Input Output Symmetric Table (IOST) at acquisition prices.

The activity sectors considered in the IOST (60 altogether) have been reduced to 31, because the available data about sectoral energy consumption was divided into 30 sectors. In these data, the sectors of production and distribution of electricity, production and distribution of gas and hot water and water collection and supply were aggregated, so we used the information available in DGEG, Balanços energéticos-1999, to disaggregate it. In Table 6 we present the economic sectors, its nomenclature and the code.

We chose the year 1999 because it was the only one for which we had a symmetrical Input-Output matrix at acquisition prices for the Portuguese economy. The cells referring to the families, society and NPISH, have been aggregated for simplification of the SAM and the model. The costs of this simplification for the simulation are null, since we do not intend to get individual results for each one of these three economic agents.

The SAM had the sectors of electricity, gas and hot water aggregated, and we wanted to have them separate, at least the sector of electricity and gas, for policy simulation. The Instituto Nacional de Estatística (INE) didn't have this data available for the year of 1999, but only for the years 2000 and forward, in I-O tables.

We disaggregated of the sector "Electricity, gas and hot water" in (i) Production and distribution of electricity and (ii) Production and distribution of gas and hot water. We arrived at the disaggregated values for the year 1999 in the following way: we calculated the weights of each sector in the aggregate "electricity, gas and hot water" for year 2000; we divided the line/column of "electricity, gas and hot water" of 1999 in two new lines/columns, (i) Production and distribution of electricity and

(ii) Production and distribution of gas and hot water”, attributing to each one the weight that it had in the aggregate for year 2000.

The I-O table for 2000 did not have, for the electricity sector and for the gas and hot water sector, disaggregated data about (i) SSC paid by employees, (ii) taxes and subsidies on products and production (iii) exportations and importations and (iv) CNR, so we could not use the previous procedure for these variables. In the first case, we distributed the values proportionally to the wages. In the second case, disaggregation existed only for total taxes and total subsidies; we distributed the taxes and subsidies on products and on production proportionally to production (taking into account that the value added tax is the same for electricity and gas). In the third case, we applied to the 1999 data the weights of the importations and exportations of electricity and gas on the total importations and total exportations of the aggregated sector for the year 2000. In the last case, we used the weights of households' final consumption disaggregated for the electricity and the gas and hot water, on the total expenditures in the aggregate of these sectors.

We aggregated the sectors of “Other activities of collective, social and personal services” with “Activities of households as employers; undifferentiated goods and services producing activities of households for own use”.

For the calculation of the CO2 emissions of each sector, we started by introducing in the INE the data for 1999 on fossil fuel consumption[42]: coal, refined oil products and natural gas (inside of refined oil products we considered fueloil, gasoil, gasoline, gpl and other energy products). Then, we associated with each type of fuel conversion factors of GJ in CO2 emissions, using coefficients of emission (see Table 4). We calculated for the year 1999 a total of 60.722.710,6 tons metric of CO2 emissions. This number is similar to the offered in INE for the year 1999 (66.119.600,0), which means a deviation of 8% for our estimative. In Table 5 we present sectoral CO2 emissions. Table 7 is the SAM for the year 1999 of the Portuguese economy that we used to calibrate the general

[42] INE, NAMEA – Energia (Conta Satélite do Ambiente)

equilibrium model and the subsequent simulations. The monetary data are valued in million Euros.

Table 4 - emission factors of CO_2 emissions (ton) by energy (Gj)

Coal	100
Natural gas	55
Fueloil	76
gasoil	73
Gasoline	73
GPL	65

Source: Own elaboration with data of Corine Aire (1991)

Table 5 - Sectoral CO_2 Emissions

	CO2 emissions	**%**
AGRSIL	992.207,4	1,6%
PESCA	354.427,7	0,6%
EXTENE	136,1	0,0%
EXTRAC	196.987,4	0,3%
ALITAB	1.321.104,7	2,2%
TEXTIL	1.221.656,6	2,0%
COURO	24.495,6	0,0%
MADCOR	425.379,5	0,7%
PAPIMP	1.023.411,3	1,7%
REFPET	2.828.110,2	4,7%
QUIMIC	1.132.745,5	1,9%
PLAST	69.173,1	0,1%
MINER	4.156.709,9	6,8%
METAL	563.328,8	0,9%
MAQEQU	332.009,8	0,5%
EQUIEL	16.188,1	0,0%
MATRANS	30.490,2	0,1%
INDTRAN	63.083,0	0,1%
ELECT	23.246.077,8	38,3%
GAS	12.369,1	0,0%
AGUA	2.930,7	0,0%
CONST	2.462.964,8	4,1%
COMER	1.464.831,6	2,4%
RESTA	613.513,5	1,0%
TRANSCO	5.576.809,9	9,2%
FINAN	13.571,8	0,0%
IMOBALU	646.214,2	1,1%
ADMPUB	1.072.139,2	1,8%
EDUCA	82.588,2	0,1%
SAUDE	1.762.743,5	2,9%
SERVI	219.342,6	0,4%
HOUSEHOLDS	8.794.969,0	14,5%
TOTAL	**60.722.710,7**	100,0%

Source: Own elaboration

Table 6 - Sectors considered in SAM 1999 and the corresponding nomenclature in National Accounts

Sectors in SAM 1999	Description	Nomenclature national accounts P60
AGRSIL	Agriculture, animal production, hunting and forestry	01,02
PESCA	Fishing	05
EXTENE	Extraction of energetic products	11
EXTRAC	Mining with exception of energetic products	12
ALITAB	Manufacture of food products, beverages and tobacco products	15,16
TEXTIL	Manufacture of textiles	17,18
COURO	Manufacture of leather and related products	19
MADCOR	Manufacture of wood and of products of wood and cork, except furniture;	20
PAPIMP	Manufacture of paper and paper products; Printing and reproduction of recorded media	21,22
REFPET	Manufacture of coke and refined petroleum products and nuclear combustible	23
QUIMIC	Manufacture of chemicals and chemical products and synthetic or artificial fibres	24
PLAST	Manufacture of rubber and plastic products	25
MINER	Manufacture of other non-metallic mineral products	26
METAL	Manufacture of basic metals	27,28
MAQEQU	Manufacture of machinery and equipment n.e.c.	29
EQUIEL	Manufacture of electric equipment and optical products	30,31,32,33
MATRANS	Manufacture of transport equipment	34,35
INDTRAN	Other manufacturing	36,37
ELECT	Production and distribution of electricity	401
GAS	Production and distribution of gas and hot water	402,403
AGUA	Water collection and supply	41
CONST	Construction	45
COMER	Wholesale and retail trade and repair of motor vehicles, motorcycles and domestic and personal use goods	50,51,52
RESTA	Accomodation and food service activities	55
TRANSCOM	Transports, storage and communications	60,61,62,63,64
FINAN	Financial and insurance activities + financial intermediation services indirectly measured (FISIM)	65,66,67
IMOBALU	Real estate Activities, leasing and business support activities	70,71,74
ADMPUB	Public administration and defence; compulsory social security	75
EDUCA	Education	80
SAUDE	Health and social work activities	85
SERVI	Other activities of collective, social and personal services + Activities of households as employers; undifferentiated goods and services producing activities of households for own use	72,73,90,91,92,93, 95

Source: Own Elaboration

Table 7 - Social and Environmental Accounting Matrix for Portugal, 1999

(Values in million Euros and CO2 emissions in tons)

			1	2	3	4	5
1	Goods and Services	AGRSIL	579,9	0,0	0,0	0,0	3.442,3
2		PESCA	0,0	40,8	0,0	0,0	72,2
3		EXTENE	0,4	0,0	0,0	0,0	0,0
4		EXTRAC	0,0	0,0	0,0	9,4	3,0
5		ALITAB	1.053,9	0,0	0,0	0,0	2.869,9
6		TEXTIL	0,1	2,5	0,0	12,4	9,9
7		COURO	0,0	0,0	0,0	0,0	0,0
8		MADCOR	3,3	0,0	0,0	0,2	10,8
9		PAPIMP	22,1	7,2	0,0	6,7	294,4
10		REFPET	157,2	25,9	0,0	42,3	54,7
11		QUIMIC	295,9	2,4	0,0	26,6	31,5
12		PLAST	0,0	2,1	0,0	0,0	172,8
13		MINER	19,2	0,0	0,0	0,0	107,6
14		METAL	7,3	3,1	0,0	9,1	162,0
15		MAQEQU	49,2	0,3	0,0	11,5	66,5
16		EQUIEL	0,2	0,7	0,0	0,2	0,2
17		MATRANS	0,0	0,2	0,0	0,1	0,0
18		INDTRAN	0,0	0,0	0,0	0,0	0,0
19		ELECT	66,3	3,1	0,0	21,7	60,5
20		GAS	3,2	0,0	0,0	1,7	7,7
21		AGUA	0,0	0,1	0,0	0,3	18,7
22		CONST	51,4	4,7	0,0	23,2	43,8
23		COMER	1.360,1	276,5	24,9	125,1	3.941,8
24		RESTA	1,2	0,7	0,0	5,3	22,3
25		TRANSCO	33,1	5,2	0,0	43,8	126,9
26		FINAN	25,6	5,7	0,0	15,5	87,8
27		IMOBALU	89,2	11,7	0,0	32,5	783,5
28		ADMPUB	0,0	0,0	0,0	0,0	0,0
29		EDUCA	0,5	1,1	0,0	4,0	38,3
30		SAUDE	26,4	0,1	0,0	0,5	13,9
31		SERVI	1,8	0,4	0,0	1,8	12,2
32	Generation of Income	Compensation of Employees	371,0	118,2	0,0	156,3	1.333,6
33		Net Operating Surplus/ Mixed Income (capital)	2.809,0	255,7	0,0	190,2	1.838,8
34		SSC paid by firms	72,0	23,0	0,0	30,3	258,9
35		Product Taxes	148,0	25,3	0,3	23,9	2.189,2
36		Product Subsidies	-433,1	-1,7	0,0	0,0	-107,6
37		Production Taxes	5,1	0,8	0,0	1,9	23,8
38		Production Subsidies	-192,5	-18,0	0,0	-3,6	-45,2
39	Allocation of Primary Income	Private Sector	0,0	0,0	0,0	0,0	0,0
40		Public Sector	0,0	0,0	0,0	0,0	0,0
41	Transfers	Property Rents	0,0	0,0	0,0	0,0	0,0
42		Rent Tax	0,0	0,0	0,0	0,0	0,0
43		SSC	0,0	0,0	0,0	0,0	0,0
44		Social Benefits	0,0	0,0	0,0	0,0	0,0
45		Current Transfers	0,0	0,0	0,0	0,0	0,0
46	Use of Income	Private Sector	0,0	0,0	0,0	0,0	0,0
47		Public Sector	0,0	0,0	0,0	0,0	0,0
48	Financial Accounts	Gross Capital Formation	0,0	0,0	0,0	0,0	0,0
49	Rest of the World	CNR	0,0	0,0	0,0	0,0	0,0
50		RW	1.803,6	135,5	1.891,2	125,6	3.397,5
51	CO2 Emissions	Coal	0,0	0,0	0,0	0,0	0,0
52		Refined Petroleum Products	992.198,7	354.427,7	136,1	196.447,5	1.261.610,6
53		Natural Gas	8,7	0,0	0,0	539,9	59.494,1
54		Total CO2	992.207,4	354.427,7	136,1	196.987,4	1.321.104,7

	6	7	8	9	10	11	12	13
1	259,8	0,9	647,0	242,9	0,0	3,5	10,9	0,0
2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
3	0,0	0,0	0,0	0,0	1.513,2	0,0	0,0	15,3
4	0,0	0,0	0,0	13,7	0,0	18,9	0,0	366,5
5	0,0	69,8	0,0	9,1	0,0	16,5	0,0	0,0
6	4.141,8	62,6	1,4	6,2	4,8	22,8	33,4	17,0
7	17,5	1.100,5	0,0	0,0	0,0	0,0	0,0	0,0
8	2,1	1,0	713,9	15,0	0,0	1,5	3,6	13,9
9	76,7	38,2	26,6	1.349,6	3,6	68,1	18,6	75,2
10	76,9	6,6	30,6	16,4	114,4	155,6	10,6	21,8
11	489,0	128,3	61,4	174,4	73,0	1.344,7	693,4	189,6
12	33,3	94,5	20,6	52,6	0,0	36,3	226,9	30,3
13	0,0	0,0	0,6	0,0	0,0	10,2	8,6	713,3
14	22,8	19,1	9,0	9,6	0,0	89,7	24,0	110,6
15	57,7	13,1	17,6	0,6	0,3	15,7	16,2	154,2
16	0,0	0,0	0,0	0,0	0,0	0,2	0,3	0,0
17	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
18	68,7	1,3	0,4	16,1	0,6	0,0	7,9	17,6
19	110,6	14,5	14,4	210,6	77,3	15,9	31,1	82,2
20	20,6	1,1	2,4	8,7	0,0	10,3	1,0	78,0
21	3,0	0,5	0,6	1,4	1,1	3,1	0,5	2,7
22	36,7	9,9	20,6	30,2	14,3	24,1	12,9	52,2
23	2.568,3	461,1	227,8	952,4	1.246,6	1.792,4	749,7	311,9
24	25,9	11,7	12,3	25,8	0,9	19,3	12,9	8,9
25	99,2	19,9	63,3	191,5	86,6	60,8	38,1	90,2
26	105,8	19,2	46,4	31,2	15,0	47,2	15,1	39,3
27	328,9	53,7	54,2	417,6	45,0	480,5	92,8	161,6
28	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
29	32,7	5,7	5,9	19,6	9,9	26,1	7,4	18,4
30	2,6	0,6	0,5	5,4	0,0	0,8	0,8	1,3
31	12,9	2,7	2,4	80,8	8,2	11,0	2,8	5,3
32	1.758,9	472,9	385,1	687,0	13,7	483,4	268,7	686,4
33	1.106,7	278,2	392,9	594,8	-14,0	274,9	166,9	707,1
34	341,5	91,8	74,8	133,4	2,7	93,9	52,2	133,3
35	663,2	144,2	78,3	123,1	3.166,2	352,0	85,1	208,5
36	-1,5	0,0	0,0	-2,1	0,0	0,0	0,0	0,0
37	13,0	3,2	3,9	6,1	2,7	8,0	3,3	9,7
38	-63,7	-15,2	-13,9	-21,8	0,0	-5,6	-6,3	-17,6
39	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
40	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
41	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
42	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
43	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
44	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
45	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
46	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
47	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
48	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
49	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
50	2.737,1	763,4	375,5	1.063,0	679,7	3.760,1	1.220,8	597,9
51	0,0	0,0	0,0	0,0	0,0	0,0	0,0	964.262,4
52	1.188.630,5	24.405,9	423.408,0	1.006.303,2	2.828.110,2	1.040.651,6	69.084,3	2.063.927,7
53	33.026,0	89,6	1.971,5	17.108,1	0,0	92.093,8	88,8	1.128.519,8
54	1.221.656,6	24.495,6	425.379,5	1.023.411,3	2.828.110,2	1.132.745,5	69.173,1	4.156.709,9

	14	15	16	17	18	19	20	21	22
1	0,0	0,1	0,0	0,3	0,0	0,0	0,0	0,0	0,0
2	0,0	0,0	0,0	0,0	0,3	0,0	0,0	0,0	0,0
3	24,9	0,0	0,0	0,0	0,0	179,3	173,6	0,0	0,0
4	17,8	0,1	0,0	0,0	0,0	0,0	0,0	0,0	312,8
5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
6	6,3	3,1	12,7	57,2	166,8	15,3	0,3	0,0	118,9
7	0,0	0,0	0,0	1,0	20,6	0,0	0,0	0,0	0,0
8	39,8	2,6	2,5	4,5	255,2	0,0	19,3	0,0	783,0
9	33,8	16,7	21,1	37,0	58,0	0,6	0,2	7,8	58,9
10	42,7	12,4	7,3	6,3	41,5	249,2	4,4	22,7	683,2
11	44,7	26,6	60,1	51,9	55,3	1,0	0,0	37,5	295,7
12	44,5	79,4	419,7	161,4	108,6	0,0	0,0	1,1	189,8
13	11,9	33,8	20,5	118,9	14,5	0,0	0,0	0,0	2.537,7
14	1.326,3	482,0	359,8	591,3	232,6	6,6	3,1	10,4	1.237,3
15	43,9	854,7	36,9	62,9	12,6	0,0	0,0	13,7	461,8
16	0,1	221,3	1.798,7	336,5	9,2	54,9	14,1	0,0	363,2
17	0,0	4,8	0,3	1.916,9	1,3	0,0	0,0	0,0	0,0
18	83,5	3,7	0,1	177,0	278,0	1,0	0,3	0,3	101,4
19	72,1	19,2	22,1	19,3	18,1	1.879,8	1,3	17,8	48,0
20	22,9	2,3	1,7	2,2	1,1	169,3	0,0	0,0	1,6
21	3,6	1,4	1,6	1,6	1,2	0,5	0,1	71,0	12,8
22	25,8	12,8	16,7	11,2	11,5	0,8	0,0	1,4	6.009,5
23	785,3	1.277,1	1.551,3	1.243,9	1.212,8	0,1	0,0	8,7	64,6
24	31,5	25,7	23,7	6,8	16,8	2,5	0,7	3,1	138,7
25	54,4	41,4	63,1	24,7	32,5	20,0	22,4	30,0	177,1
26	20,3	79,9	37,4	18,4	26,8	57,8	6,1	3,8	212,2
27	132,9	105,0	209,0	85,4	130,5	197,5	11,4	16,5	720,0
28	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
29	22,7	15,8	51,7	30,5	6,7	0,8	0,0	2,1	39,3
30	1,4	1,2	1,4	0,6	0,8	0,2	0,0	0,1	12,4
31	5,1	17,7	55,8	14,3	2,2	67,8	3,2	3,3	14,1
32	575,2	276,2	812,1	598,6	454,9	456,2	41,2	137,2	3474,3
33	420,7	202,7	307,6	391,2	275,0	1.935,2	131,2	143,9	3.279,7
34	111,7	53,6	157,7	116,2	88,3	88,6	8,0	26,6	674,6
35	131,2	180,6	480,5	2.109,5	361,5	98,2	8,1	16,1	659,3
36	-1,8	0,0	0,0	-8,1	0,0	0,0	0,0	-7,3	0,0
37	5,2	4,6	5,9	10,5	3,7	12,8	1,1	0,5	26,8
38	-16,3	-5,7	-15,0	-9,1	-13,9	-3,8	-0,3	-0,4	-83,8
39	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
40	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
41	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
42	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
43	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
44	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
45	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
46	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
47	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
48	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
49	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
50	2.814,9	3.524,5	5.357,6	7.382,2	873,6	119,6	1,4	1,7	3,5
51	0,0	0,0	0,0	0,0	0,0	13.619.430,4	0,0	0,0	0,0
52	513.765,8	291.820,0	16.005,8	30.399,5	63.048,3	5.658.961,9	12.369,1	2.930,7	2.462.514,8
53	49.563,0	40.189,8	182,3	90,7	34,6	3.967.685,4	0,0	0,0	450,0
54	563.328,8	332.009,8	16.188,1	30.490,2	63.083,0	23.246.077,8	12.369,1	2.930,7	2.462.964,8

	23	24	25	26	27	28	29	30
1	0,0	304,5	0,0	0,0	0,0	10,3	1,8	88,7
2	0,0	94,2	0,0	0,0	0,0	0,0	0,0	1,1
3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
4	0,0	5,4	0,0	0,0	0,0	0,0	0,9	0,0
5	0,1	2.361,5	0,0	0,0	0,0	49,8	35,6	316,1
6	231,9	120,8	37,7	0,0	21,8	18,0	2,8	136,5
7	14,1	0,0	0,8	0,0	0,0	1,2	0,1	0,3
8	97,3	2,2	0,0	0,0	19,1	0,0	0,5	0,3
9	618,4	14,7	93,0	111,1	1.017,2	5,0	83,3	123,5
10	323,0	247,9	856,3	2,7	153,0	223,2	27,2	457,1
11	209,5	53,4	4,0	3,5	52,3	3,7	13,4	942,3
12	359,7	1,1	18,1	0,0	257,0	0,2	1,4	1,6
13	93,0	54,2	0,3	0,0	58,3	0,0	7,4	0,6
14	405,1	42,1	0,5	0,0	149,4	0,0	5,0	25,0
15	87,2	33,6	0,3	0,0	48,6	48,7	3,9	13,7
16	430,3	120,2	215,6	102,4	18,0	39,3	27,5	121,7
17	432,5	10,1	109,4	0,0	0,5	50,3	1,0	4,1
18	276,6	73,2	0,3	18,6	9,4	69,4	37,0	15,4
19	340,4	176,1	92,8	54,2	273,9	136,4	104,0	59,7
20	0,4	11,1	0,3	0,0	0,2	0,3	1,3	1,1
21	37,5	40,5	7,8	3,5	16,1	53,7	21,2	21,6
22	160,0	21,0	189,9	35,4	677,9	27,4	25,6	22,7
23	1.095,5	108,4	104,2	6,4	112,7	41,9	12,3	42,8
24	549,5	36,8	102,9	116,2	333,3	129,0	61,8	88,5
25	2.106,4	73,3	1.966,1	237,5	575,5	254,9	130,6	162,2
26	393,7	46,6	95,9	5.013,1	313,1	9,3	7,6	19,2
27	2.633,8	437,7	743,9	1.492,3	4.112,9	366,7	547,1	610,9
28	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
29	89,7	23,1	104,4	16,0	49,4	17,8	8,6	2,4
30	21,6	4,5	3,4	0,0	64,7	2,5	12,9	365,4
31	152,8	125,1	236,8	182,8	1.417,5	111,7	91,9	97,8
32	5.154,6	1439,2	2.632,8	2.268,4	2.493,3	5494,8	5045,9	3177,0
33	7.454,4	1.139,2	3.020,4	-1.720,9	11.148,9	1.115,5	648,3	1.485,6
34	1.000,9	279,5	511,2	440,5	484,1	1066,9	979,8	616,9
35	363,8	733,7	485,7	509,7	1.917,9	0,0	8,5	36,7
36	0,0	0,0	-96,4	0,0	-12,5	0,0	-12,4	0,0
37	59,5	12,5	40,7	10,6	359,8	0,0	4,9	5,4
38	-123,1	-41,2	-105,6	-6,0	-503,4	0,0	-99,9	-16,2
39	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
40	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
41	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
42	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
43	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
44	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
45	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
46	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
47	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
48	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
49	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
50	313,9	347,3	805,6	251,9	1.022,7	0,0	0,0	0,0
51	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
52	1.464.831,6	566.679,0	5.576.809,9	13.571,8	644.162,4	1.068.939,1	82.588,2	1.740.531,0
53	0,0	46.834,5	0,0	0,0	2.051,8	3.200,1	0,0	22.212,5
54	1.464.831,6	613.513,5	5.576.809,9	13.571,8	646.214,2	1.072.139,2	82.588,2	1.762.743,5

	31	32	33	34	35	36	37	38	39	40
1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
2	0,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
4	0,3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
5	0,5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
6	47,3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
8	85,6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
9	149,7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
10	63,7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
11	161,4	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
12	34,6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
13	2,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
14	24,5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
15	0,4	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
16	151,7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
17	4,6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
18	66,6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
19	122,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
20	13,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
21	35,3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
22	73,7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
23	23,4	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
24	54,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
25	308,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
26	82,7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
27	1.456,7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
28	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
29	18,7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
30	12,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
31	450,6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
32	2.355,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
33	1.635,6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
34	457,3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
35	707,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
36	-114,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
37	25,7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
38	-118,7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
39	0,0	43.649,8	39.604,5	1.093,2	0,0	0,0	0,0	0,0	0,0	0,0
40	0,0	0,0	2.010,8	7.377,0	15340,8	-315,7	671,4	-1503,1	0,0	0,0
41	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	21.410,7	3.589,6
42	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	10.606,5	0,0
43	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	7.039,0	0,0
44	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	2.830,6	12.839,9
45	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	4.542,6	13.410,8
46	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	87.133,0	0,0
47	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	22.658,2
48	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
49	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
50	544,4	119,2	0,0	0,0	674,7	-482,8	0,0	-62,9	0,0	0,0
51	0,0									
52	214.504,8									
53	4.837,8									
54	219.342,6									

	41	42	43	44	45	46	47	48	49	50
1	0,0	0,0	0,0	0,0	0,0	2.218,9	0,0	352,1	66,3	200,5
2	0,0	0,0	0,0	0,0	0,0	637,3	0,0	0,0	19,0	68,0
3	0,0	0,0	0,0	0,0	0,0	0,1	0,0	9,6	0,0	0,0
4	0,0	0,0	0,0	0,0	0,0	8,3	0,0	1,5	0,2	159,6
5	0,0	0,0	0,0	0,0	0,0	12.542,9	0,0	174,5	374,9	1.469,3
6	0,0	0,0	0,0	0,0	0,0	4.732,0	0,0	-11,0	141,4	4.973,8
7	0,0	0,0	0,0	0,0	0,0	1.010,5	0,0	-4,8	30,2	1.683,1
8	0,0	0,0	0,0	0,0	0,0	96,5	0,0	18,9	2,9	1.080,5
9	0,0	0,0	0,0	0,0	0,0	918,9	0,7	-27,9	27,5	1.108,3
10	0,0	0,0	0,0	0,0	0,0	2.409,6	0,0	23,2	72,0	424,3
11	0,0	0,0	0,0	0,0	0,0	1.586,2	964,2	2,0	47,4	1.115,7
12	0,0	0,0	0,0	0,0	0,0	740,5	0,0	109,9	22,1	590,1
13	0,0	0,0	0,0	0,0	0,0	166,0	0,0	32,3	5,0	886,1
14	0,0	0,0	0,0	0,0	0,0	105,7	0,0	320,7	3,2	1.141,7
15	0,0	0,0	0,0	0,0	0,0	667,3	0,0	3.540,6	19,9	1.223,3
16	0,0	0,0	0,0	0,0	0,0	1.350,9	0,0	3.085,7	40,4	3.378,2
17	0,0	0,0	0,0	0,0	0,0	5.378,5	0,0	3.586,2	160,8	3.911,7
18	0,0	0,0	0,0	0,0	0,0	2.259,6	0,0	597,1	67,5	509,7
19	0,0	0,0	0,0	0,0	0,0	1.272,8	0,0	0,0	38,0	135,8
20	0,0	0,0	0,0	0,0	0,0	84,3	0,0	0,0	2,5	1,2
21	0,0	0,0	0,0	0,0	0,0	198,7	1,2	0,0	5,9	0,5
22	0,0	0,0	0,0	0,0	0,0	86,3	0,0	14.887,6	2,6	4,6
23	0,0	0,0	0,0	0,0	0,0	2.729,3	0,0	440,2	81,6	403,0
24	0,0	0,0	0,0	0,0	0,0	3.993,1	1,6	0,0	2.521,7	168,5
25	0,0	0,0	0,0	0,0	0,0	2.976,0	15,9	0,0	197,4	1.950,9
26	0,0	0,0	0,0	0,0	0,0	1.862,9	0,0	0,0	55,7	333,8
27	0,0	0,0	0,0	0,0	0,0	6.282,1	10,5	2.846,3	386,5	575,5
28	0,0	0,0	0,0	0,0	0,0	213,4	9.130,8	0,0	3,6	0,0
29	0,0	0,0	0,0	0,0	0,0	1.187,1	5.959,5	0,0	32,9	0,0
30	0,0	0,0	0,0	0,0	0,0	3.560,6	4.831,6	0,0	97,1	0,0
31	0,0	0,0	0,0	0,0	0,0	4.333,8	337,9	600,6	265,4	207,0
32	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	147,1
33	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
34	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
35	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
36	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
37	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
38	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
39	22.395,2	0,0	2.150,2	15.651,3	9.018,0	0,0	0,0	0,0	0,0	0,0
40	1.021,3	10.606,5	4.888,8	0,0	12.400,8	0,0	0,0	0,0	0,0	0,0
41	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	3.974,8
42	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
43	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
44	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	33,2
45	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	4.793,7
46	0,0	0,0	0,0	0,0	0,0	412,8	0,0	0,0	0,0	0,0
47	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
48	0,0	0,0	0,0	0,0	0,0	19.738,7	1.404,3	0,0	0,0	2.881,1
49	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	4.791,6
50	5.558,6	0,0	0,0	52,4	1.328,3	1.784,3	0,0	-6.561,2	0,0	0,0
51						0,0				
52						8.720.141,0				
53						74.828,0				
54						8.794.968,9				

	51	52	53	54	Total
1					8.430,8
2					933,2
3					1.916,5
4					918,5
5					21.344,5
6					15.148,5
7					3.875,1
8					3.276,3
9					6.464,7
10					7.065,8
11					9.242,0
12					3.810,0
13					4.902,8
14					6.938,7
15					7.577,2
16					11.881,7
17					15.573,1
18					4.758,3
19					5.611,9
20					451,4
21					569,3
22					22.628,3
23					25.384,0
24					8.553,5
25					12.279,1
26					9.150,1
27					26.662,5
28					9.347,7
29					7.849,1
30					9.048,1
31					8.937,7
32					43.769,0
33					41.615,4
34					8.470,2
35					16.015,5
36					-798,6
37					671,4
38					-1.566,0
39					133.562,3
40					52.498,5
41					28.975,1
42					10.606,5
43					7.039,0
44					15.703,7
45					22.747,1
46					87.545,8
47					22.658,2
48					24.024,1
49					4.791,6
50					44.326,3
51					14.583.692,8
52					40.593.916,9
53					5.545.100,9
54					60.722.710,7

Source: Own Elaboration; data from INE and DGEG.

REFERENCES

DGEG (Direcção Geral de Energia e Geologia), Divisão de Estatística, Balanços energéticos 1999. In http://www.dgge.pt/

INE, NAMEA – Energia (Conta Satélite do Ambiente)

5. Effects of a Green Tax Reform in Portugal

In this chapter we describe the main contribution of the thesis, from a methodological point of view: the analysis of the economic and environmental effects of a GTR in Portugal, by means of a general equilibrium model. First we briefly remind the advantages of a GTR as well as the empirical simulations with best results. Then we present some data on environmental and labour taxes in Portugal, in order to contextualize the simulations. Then, the methodology is synthetically described, and so are the results of the model.

A GTR have the potential of improving the environment, through CO2 emissions reductions, and simultaneously raise GDP and employment, validating the "double dividend" hypothesis. This is an interesting issue as economies like Portugal have to accomplish Kyoto targets and to improve the economic situation in the present times of crisis. Therefore it is important and convenient to analyse the effects of this policy, and the existence (or not) of double or multiple dividends.

As discussed in chapter two, the simulations that were made in recent years to evaluate the economic effects of a GTR illustrate some particular characteristics that influence the final results. Our objective was to simulate the reforms with better results, so we follow some of the "advices" given by previous works.

Concerning static models (as we based our study in a static model), we saw that its results are more restrictive than those from dynamic models. The majority of the static GEM estimate negative effects on welfare and on the GDP. But the more positive results are achieved with models that recycle revenues reducing labour costs, VAT or personal income tax, "vis-à-vis" "lump-sum" transfers.

Analysing static and dynamic models results, we saw that simulations usually recycle revenues by reducing SSC, maybe because this strategy is the one that have more positive results on jobs, GDP and welfare. The GTRs that recycle environmental taxes through "lump-sum" transfers represent the second most common simulated policy.

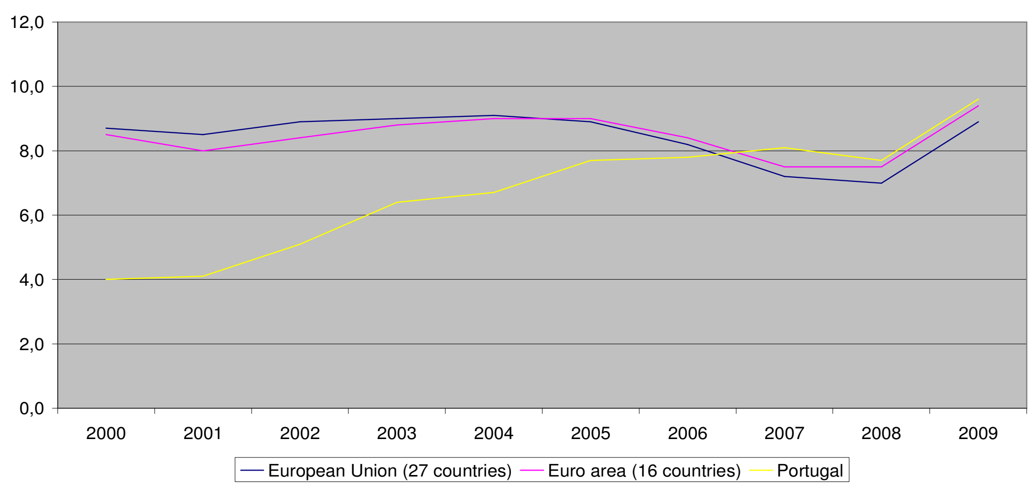
Given the previous results we decided to focus our analysis in a GTR with recycling of revenues through reducing SSC, and compare it with a GTR with lump-sum transfers.

Before presenting GTR simulations for the Portuguese economy, it is important to compare the levels of Portuguese taxes with UE levels, particularly environmental and labour taxes, which are the ones involved in this kind of reform.

To design a GTR aiming to achieve any kind of "employment double dividend", it is important to start by analysing the unemployment numbers in Portugal.

Ten years ago, the levels of unemployment in Portugal were clearly below the European average (4% versus 8,7% in 2000), but have increased quickly in recent years. Portugal crossed the European trajectory in 2006 and has since kept levels of unemployment above the average, having, in 2009, 9,6% of the workforce unemployed (8,9% for the European average).

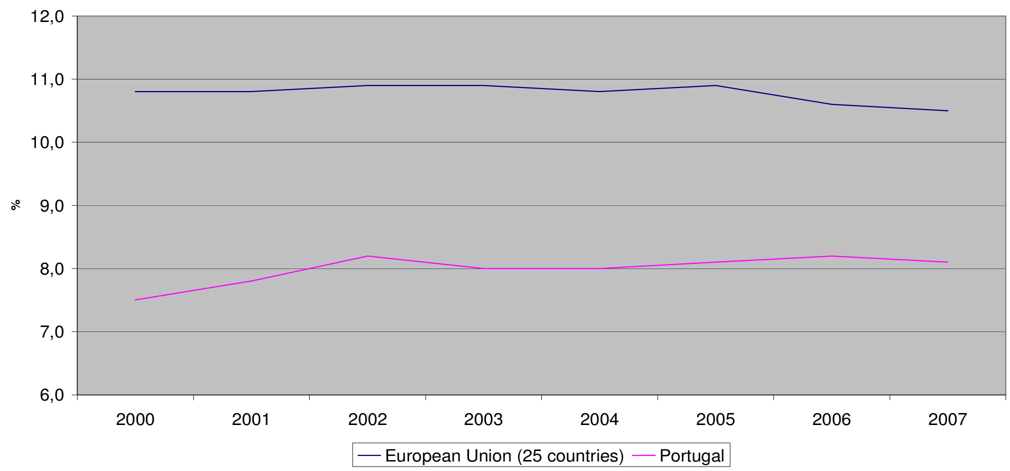
Figure 1 - Unemployment rate, annual average %



Source: Own elaboration with data from Eurostat

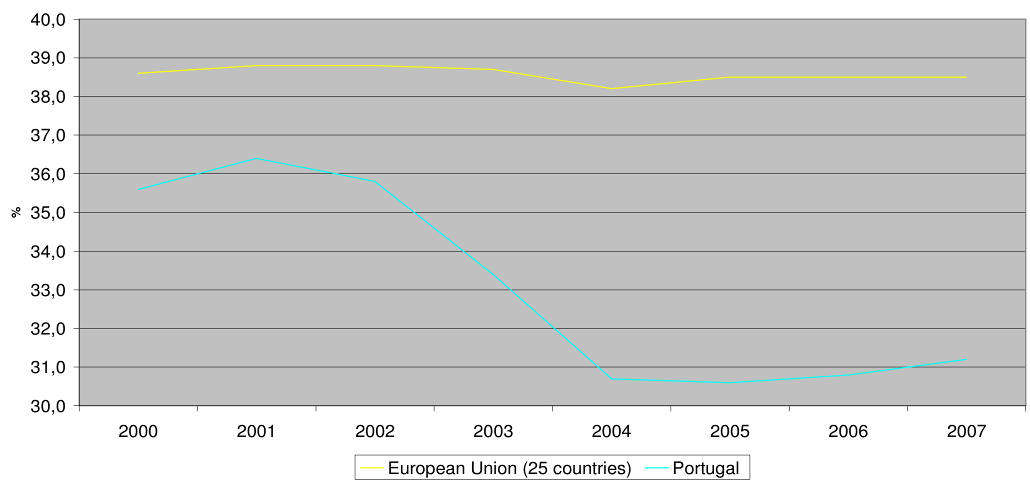
Presently, the employers' SSC amount to 23,75% of gross wages. This contribution is, both in % of GDP and in % of total receipts of social protection, lower in Portugal than in the EU-27 average. In 2007 this difference was of 2,4 and 7,3 percentage points, respectively, for each indicator. This important difference to the EU-27 average (particularly in the employers SSC in % of total receipts of social protection) was due to the strong increment of unemployment since 2001.

Figure 2 - Employers' Social Contribution % of GDP



Source: Own elaboration with data from Eurostat

Figure 3 - Employers' Social Contribution % of total receipts



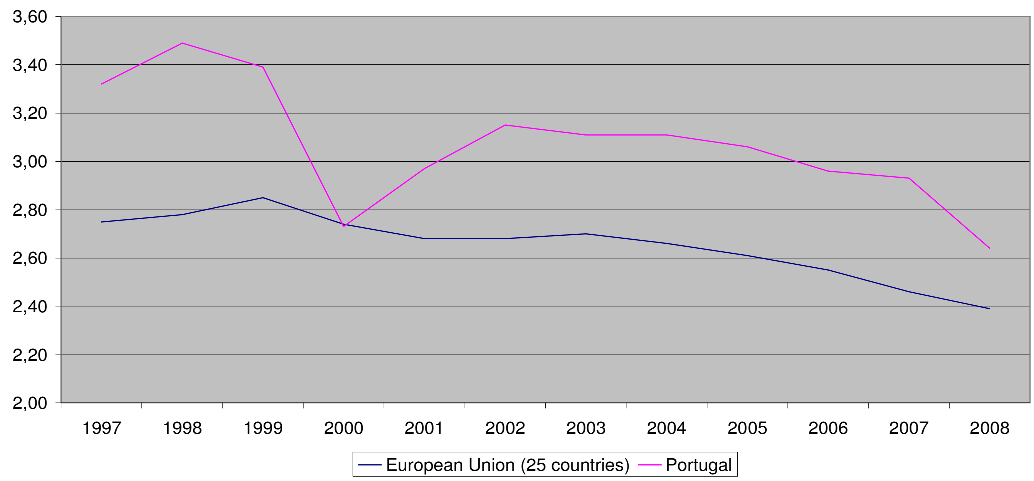
Source: Own elaboration with data from Eurostat

Regarding the environmental taxes[43], in Figure 4 we can see that revenues from total environmental taxes as percentage of the GDP have always been above the UE average (except in the year 2000). However, the values of this indicator do not mean that the environmental quality is increasing. Quite the opposite: if a tax reaches its goal (reducing the harmful behaviour) the tax base diminishes, diminishing the revenues. It may be

43 That include energy taxes, transport taxes and taxes on pollution/resources

due to higher tax rates, as it is actually the case for taxes related to transport fuels (i.e., much higher than in Spain, as everybody living near the border knows).

Figure 4 - Total environmental taxes in % of GDP



Source: Own elaboration with data from Eurostat

It is important to distinguish two periods: before 2004 we see that environmental tax revenues diminished, although energy consumption rose more than GDP (see Figure 5). This might have happened due to the maintenance of oil prices in steady levels or with a slight decreasing trend until 2004, which allowed the weight of energy expenses in GDP to remain steady. After 2004, the reduction of environmental tax revenues on GDP could be due to an energy increment smaller than the GDP growth, as almost all of environmental revenues come from energy taxes. On the other side, innovations in policy instruments, like CO2-emissions trading, also influence the reduction of environmental tax revenue (European Commission, 2007).

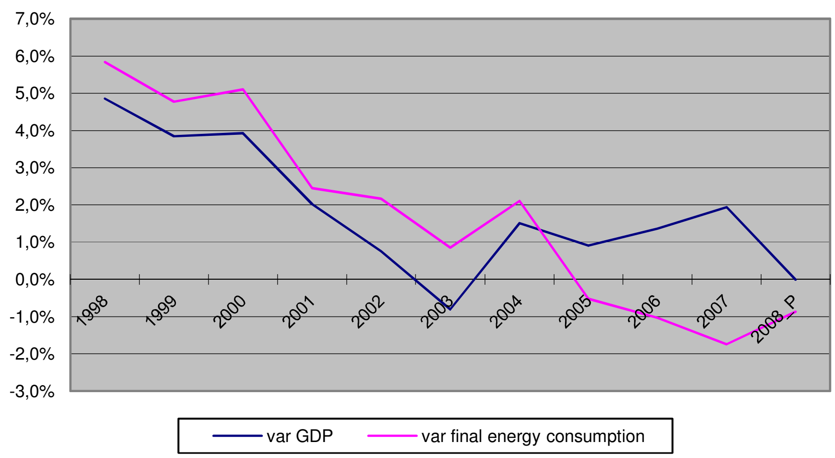
Regarding the structure of environmental taxes in Portugal, we should say that pollution taxes practically do not exist (0,01% of total environmental taxes) while energy taxes predominate (73% of total environmental taxes)[44].

The existing GTR experiences reveal that, by increasing energy taxes or CO2 taxes, it is feasible to design a more efficient tax system. In the case of Portugal, energy taxes for transport purposes are already at a

[44] According to data from Direcção-Geral de Geologia e Energia, the main consumption of final energy in 2008 was for transport (36%), so we can infer that the bigger part of energy taxes comes from the transport sector.

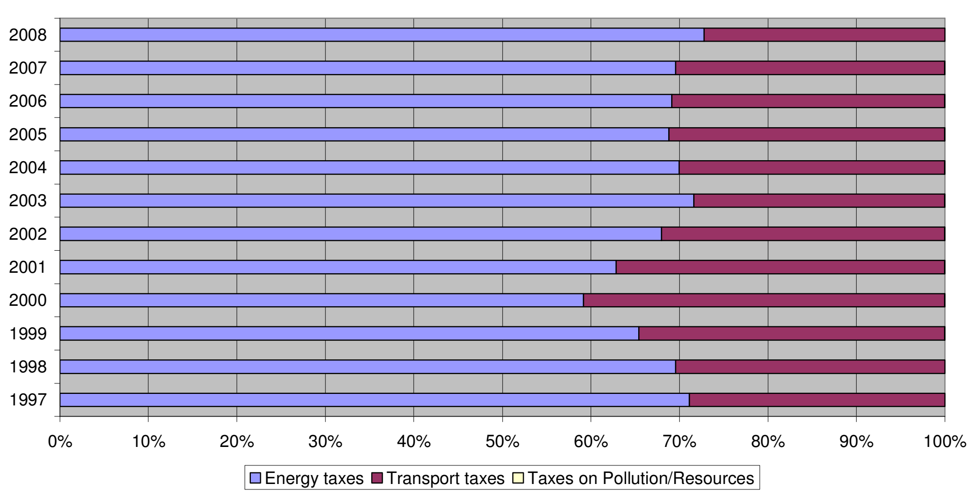
high level. But a restructuring of energy taxes could be designed with no increase in the global rate, just to make them more efficient, namely through their effect in agent's behaviour. Moreover, there is a high burden of energy taxes in the transport sector, which represents also one of the main energy consumers in Portugal. So energy taxes for other uses (domestic or industrial use, electricity generation) could be raised. Actually the European Commission published that about 30% of GHG emissions are made by the domestic and services sectors, through energy requirements of buildings. As in Portugal pollution taxes are practically inexistent, the CO2 tax applied indirectly through the fossil fuels taxation would be a good bet.

Figure 5 - GDP and final energy consumption annual variation rate



Source: DGEG, Balanços Energéticos and INE, Contas Nacionais Anuais

Figure 6 - Environmental taxes in Portugal



Source: Own elaboration with data from Eurostat

5.1 The simulated environmental policies

We analyze the environmental and socioeconomic effects of two environmental policies to contain climate change; these are the policies usually analysed in empirical literature.

Firstly, we study the effects of a new environmental tax within the most general framework of a GTR. The income generated by the environmental tax, finances a reduction in the social contributions in charge of the employers, maintaining the public budget balance in real terms.

Afterwards, we obtain the effects of an environmental tax when the receipts generated are given back to the citizens, by means of lump sum transfers. This alternative environmental policy is also subject to the restriction of constant public budget balance. In both reforms, the simulation was made for an environmental tax of 20€, because this value is similar not only to other carbon taxes in place in other countries, but also to the expected prices of carbon allowances in the EU ETS during phase II (although this price dropped in reality, mainly due to the economic crisis) and the expected price for the next Kyoto phase. Furthermore, this is the value proposed for the European Commission in April 2011, for a CO2 emission tax for energy products[45].

An important question in the design of both policies is the way in which the environmental tax can be implemented. The design of this tax as an instrument to reduce the CO2 emissions must follow a pragmatic approach. In this sense, the environmental tax does not have to burden directly the emissions that each productive sector or each home causes with daily activity; instead, it may tax the consumption of certain primary energy goods, according to their carbon content. These goods (coal, refined products of petroleum, and natural gas) are the origin of the CO2 emissions that take place during their combustion.

As mentioned in chapter three, there is a relation of proportionality between the physical units consumed of different fossil fuels and the emissions of CO2 to the atmosphere, which causes a tax on the fossil fuel consumption to be equivalent to a tax that burdens the CO2 emissions directly.

[45] EUROPEAN COMMISSION, 2011

5.2. The effects of a GTR with reduction in the social contributions

The immediate effect of the GTR is a −23,3% reduction in the marginal value of the social contributions in charge of the employers (equivalent to a new tax of 18,2%). As a result we obtain lower wage costs. This stimulates a greater demand of labour by the different productive sectors. The level of employment increases in +0,8%, which means almost 45 thousand new jobs[46]. A greater rate of employment also creates tensions in the labour market, so the real income of labour increases +1,6%. These numbers represent a very conservative estimation. The lector should keep in mind that our model assumes a Portuguese economy without unemployment. In the actual circumstances, the new jobs generated by this reform will be greater with a small or null impact on labour income (wages) and therefore lower impact on prices, as long as the unemployment rates in 2010 guarantee no tensions in the labour market.

The Gross Domestic Product in acquisition prices (GDPpa), i.e., at consumer prices including taxes and subsidies, experiences a growth of +0,9% but diminishes −0,4% in real terms.

For a more precise understanding of the effects on economic activity, we have calculated an "Activity Index", which weighs the variations of production in each sector by its importance on total production at the benchmark situation. This index shows that economic activity after the GTR will represent 99,24% of the benchmark situation (see Table 8). Therefore there is a modest impact on aggregate activity levels. The rise in employment and on real wages, combined with a lower level of activity (production) results in a slight increase in the consumer price index of +1,3%.

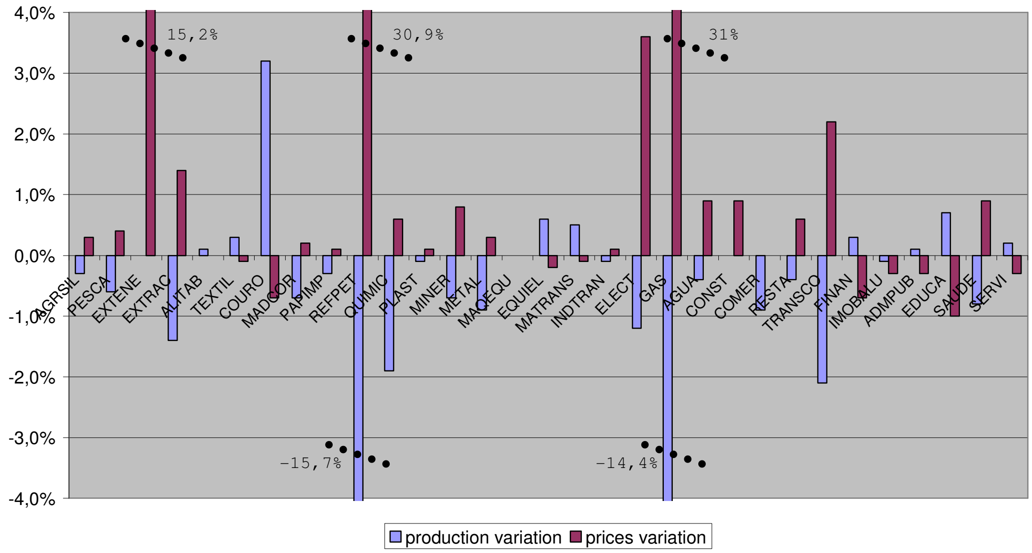
Figure 7 shows the sectoral effects of the simulated GTR in terms of variation in the production, as well as in the prices of acquisition of each one of the produced goods.

As we expected, the GTR negatively affects the level of activity of the sectors that produce and commercialize primary energy goods, like refined products of petroleum (−15,7%) and natural gas (−14,4%). It also negatively affects other sectors but in a lower magnitude, like

46 Based in INE statistics for the 2nd trimester of 2010,in Inquérito ao Emprego, http://www.ine.pt

transports and communications, electricity, mining and manufacture of chemicals.

Figure 7 - Sectoral effects of a GTR with SSC reduction and environmental tax of 20€



Source: Own elaboration

On the other hand, the sector that benefits more with the GTR is the manufacture of leather. Education, manufacture of electric equipment, manufacture of transport equipment and manufacture of textiles, all present modest ascents. This is also the case for some services, like financial services and education, which are quite intensive in labour.

In what prices are concerned, the effects of the GTR also differ between sectors. The energy products are the ones that experience the greater increases in their prices: the price of coal increases +15,2%[47]; the price of refined products of petroleum +30,9% and of natural gas +31%. It also affects the electricity sector (+3,6%) because this sector transforms primary energy sources in secondary energy sources[48], and the transport and communications sector (+2,2%). Manufacture of leather, financial and insurance activities, education and health, are among the sectors that become cheaper.

47 The increase is lower than for other energy sources because there is an important hydroelectric generation capacity than alleviates the demand for coal.
48 In 2008, this sector produced 71,1% of electricity based on thermal energy, 15,9% based on hydroelectric energy, 12,5% based on eolic energy, 0,4% on geothermal energy and 0,1% on solar energy (Source: Direcção Geral de Energia e Geologia)

In environmental terms, the GTR is an effective instrument to reduce the CO2 emissions. The CO2 emissions are reduced in -11,6%. As Table 8 shows, the electricity sector is, by far, the one that makes the biggest reduction (-1360 thousand CO2 tons), but the sectors of manufacture of chemicals, refined petroleum products, gas and other manufacturing, are the ones that make more effort in relative terms (vis-a-vis the initial level of emissions).

Table 8 - Sectoral effects in prices, production and CO2 emissions with a GTR with SSC reduction and environmental tax of 20€

	Prices	Production	CO2 emissions	
	var %	var %	var ton	var %
AGRSIL	0,3%	-0,3%	-114.156	-11,5%
PESCA	0,4%	-0,6%	-43.675	-12,3%
EXTENE	15,2%			0,0%
EXTRAC	1,4%	-1,4%	-36.560	-18,6%
ALITAB	0,0%	0,1%	-141.759	-10,7%
TEXTIL	-0,1%	0,3%	-174.772	-14,3%
COURO	-0,7%	3,2%	-2.693	-11,0%
MADCOR	0,2%	-0,7%	-73.175	-17,2%
PAPIMP	0,1%	-0,3%	-111.694	-10,9%
REFPET	30,9%	-15,7%	-584.329	-20,7%
QUIMIC	0,6%	-1,9%	-234.725	-20,7%
PLAST	0,1%	-0,1%	-8.769	-12,7%
MINER	0,8%	-0,7%	-673.592	-16,2%
METAL	0,3%	-0,9%	-85.251	-15,1%
MAQEQU	0,0%	0,0%	-47.165	-14,2%
EQUIEL	-0,2%	0,6%	-2.071	-12,8%
MATRANS	-0,1%	0,5%	-3.934	-12,9%
INDTRAN	0,1%	-0,1%	-12.123	-19,2%
ELECT	3,6%	-1,2%	-1.360.410	-5,9%
GAS	31,0%	-14,4%	-2.789	-22,5%
AGUA	0,9%	-0,4%	-316	-10,8%
CONST	0,9%	0,0%	-288.501	-11,7%
COMER	0,0%	-0,9%	-167.938	-11,5%
RESTA	0,6%	-0,4%	-65.597	-10,7%
TRANSCO	2,2%	-2,1%	-721.890	-12,9%
FINAN	-0,7%	0,3%	-1.269	-9,4%
IMOBALU	-0,3%	-0,1%	-66.529	-10,3%
ADMPUB	-0,3%	0,1%	-119.936	-11,2%
EDUCA	-1,0%	0,7%	-7.647	-9,3%
SAUDE	0,9%	-0,8%	-218.438	-12,4%
SERVI	-0,3%	0,2%	-22.403	-10,2%
TOTAL	1,3%[a]	-0,76%[b]	-7.025.080,7[c]	-11,6%[c]

Source: Own Elaboration

Notes: % prices not deflated; [a]inflation; [b]activity index; [c]aggregated variation of CO2 emissions

We consider the previous analysis, in terms of cost for the economy, as quite interesting. We were concerned with the possibility that these reductions in emissions, caused by the rise of prices of energy goods, would cause a reduction in the welfare of the consumers. For this reason, we analyzed which were the effects of the GTR in terms of welfare, measuring the hicksian equivalent variation in real terms[49]. The GTR produces a decrease of -0,3% in the non environmental welfare, i.e., the welfare not associated directly to changes in the CO2 emissions. The losses are of -327 million Euros.

Although we have seen that the level of employment and wages are better with the GTR, the loss of welfare is related to the reduction of leisure, on which the utility of the representative household partly depends. There is more labour supply and so less time for leisure. On the other side, the value of leisure in our model is equal to its opportunity cost, hourly wage, which rises with the GTR. It is worth to mention, that there is also a reduction on consumption, as long as there is a lower production level and higher consumer prices which also impact negatively on welfare.

As mentioned earlier, these numbers represent a very conservative estimation of welfare (in this case, over estimation of welfare costs, to be more precise). The lector should remember that our model assumes a Portuguese economy without unemployment. In the present circumstances, the opportunity cost for leisure should be lower, thus increasing the chances of obtaining an increase on welfare, instead.

The environmental benefits of the GTR have been measured assuming that the environmental tax expresses the monetary damages caused by the polluting emissions. That is to say, one ton of CO2 emitted to the atmosphere causes damage on the society and economic activities valued in 20 Euros by ton of CO2. This way, the environmental changes caused by the GTR would increase the environmental welfare in +141 million Euros.

As a result of the previous partial effects, the social welfare would experience a decrease of -187 million Euros, that represents a tiny loss of -0,17%.

[49] That is, the cost of the reform, for the representative household, measured at initial prices, or the compensation that he must get, to maintain initial welfare, if the prices did not change with the reform.

Concerning the trade balance (or net exports) and energy dependence towards other countries, the GTR has interesting results. The sectors whose trade balance improves more are: extraction of energy products, manufacture of leather and manufacture of electric equipment. The sectors whose net exports worsen are: refined petroleum products, transports, manufacture of chemicals and electricity.

Regarding energy sectors, we can see that net exports of refined petroleum products and electricity are smaller, but with the GTR, in contrast, we become less dependent on carbon towards other countries. Furthermore, the last effect surpasses the first, making the energy balance improve in +88 million Euros. Environmentally speaking, we can say that with these changes, we are importing less CO2 emissions. Considering the emissions linked with fossil fuel consumption, with the GTR the economy reduces imports (net of exports) by -1 Co2 million tons (this represents less -6,8% of the net imported emissions on benchmark).

As it was mention before, we should notice that our model considers full employment. In the Portuguese economy there is a considerable level of unemployment (10,9% in 3rd trimester of 2010[50]), so the effects of the GTR on the employment would be greater. Considering the same idea, the effects on GDP would also be more positive and the effects on wages and prices would be smaller. Consequently, the above results represent a very conservative scenario.

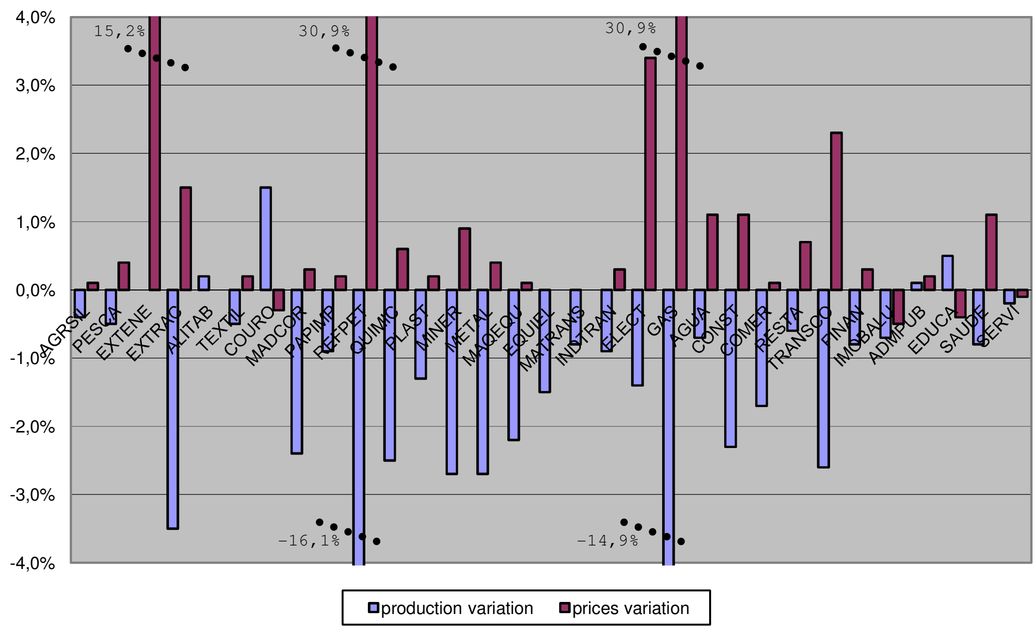
5.3 The effects of an environmental tax with lump-sum transfers

We also analyzed the results of a reform in which the income generated by the environmental tax is given back to the citizens by lump-sum transfers. In this case, the fiscal reform must have, as its only objective, to reduce CO2 emissions. As a consequence, their effects on the economy are slightly more negative than the GTR analyzed previously. The introduction of the environmental tax reduces in -1% the real wealth of the economy in terms of the real GDPpa, whereas the real Gross Domestic Product at basic prices (GDPbp) experiences a fall of -2,6%. The activity index is now of 98,54% and the level of employment and real wages are reduced by -0,5% and -2%, respectively.

[50] Source: INE

Figure 8 summarizes the sectoral effects of the environmental tax in combination with lump-sum transfers. Manufacture of leather, public administration and education, are the only sectors that are benefited (in a slight way). Among the more harmed sectors are refined petroleum products (-16,1%), natural gas (-14,9%) and mining (-3,5%). In relation to the effects of the reform on the sectoral prices of acquisition, the differences with respect to the results obtained with the GTR are of little significance. As a result, there is an increase on CPI of +1,4%.

Figure 8 - Effects of a GTR with lump sum transfers and environmental tax of 20€



Source: Own Elaboration

The environmental tax along with lump-sum transfers, allows a greater reduction in the CO2 emissions with respect to the GTR, as shown in Table 9. The emissions are reduced now in -7,3 million of tons, which represents around 0,4 percentage points more, result coherent with the kind of simulated environmental policy. Now, there is not the counterbalance effect on employment through lower SSC. The distribution of the emission reduction between the different sectors is not very different to the one shown by the GTR. The sectors that reduce more are electricity, transports, manufacture of other non-metallic mineral products and refined petroleum products. In relative terms, the sectors that make more effort are natural gas (-23,1%) refined petroleum products and manufacture of chemicals (-21%) and mining (-20,2%). In addition, it is stated that the sectors that have greater effort reducing their emissions with respect to the levels reached with the GTR, were indeed the most harmed sectors in production terms.

Table 9 - Sectoral effects in prices, production and CO2 emissions with a GTR with lump sum transfers and environmental tax of 20€

	Prices	Production	CO2 emissions	
	var %	var %	var ton	var %
AGRSIL	**0,1%**	**-0,4%**	-116.478	-11,7%
PESCA	**0,4%**	**-0,5%**	-43.545	-12,3%
EXTENE	**15,2%**			0,0%
EXTRAC	**1,5%**	**-3,5%**	-39.849	-20,2%
ALITAB	**0,0%**	**0,2%**	-141.109	-10,7%
TEXTIL	**0,2%**	**-0,5%**	-180.659	-14,8%
COURO	**-0,3%**	**1,5%**	-2.993	-12,2%
MADCOR	**0,3%**	**-2,4%**	-78.852	-18,5%
PAPIMP	**0,2%**	**-0,9%**	-115.595	-11,3%
REFPET	**30,9%**	**-16,1%**	-594.801	-21,0%
QUIMIC	**0,6%**	**-2,5%**	-237.695	-21,0%
PLAST	**0,2%**	**-1,3%**	-9.280	-13,4%
MINER	**0,9%**	**-2,7%**	-739.420	-17,8%
METAL	**0,4%**	**-2,7%**	-93.253	-16,6%
MAQEQU	**0,1%**	**-2,2%**	-52.743	-15,9%
EQUIEL	**0,0%**	**-1,5%**	-2.292	-14,2%
MATRANS	**0,0%**	**-0,8%**	-4.197	-13,8%
INDTRAN	**0,3%**	**-0,9%**	-12.355	-19,6%
ELECT	**3,4%**	**-1,4%**	-1.427.680	-6,1%
GAS	**30,9%**	**-14,9%**	-2.855	-23,1%
AGUA	**1,1%**	**-0,7%**	-322	-11,0%
CONST	**1,1%**	**-2,3%**	-338.035	-13,7%
COMER	**0,1%**	**-1,7%**	-177.824	-12,1%
RESTA	**0,7%**	**-0,6%**	-66.015	-10,8%
TRANSCO	**2,3%**	**-2,6%**	-745.921	-13,4%
FINAN	**0,3%**	**-0,8%**	-1.206	-8,9%
IMOBALU	**-0,5%**	**-0,7%**	-71.173	-11,0%
ADMPUB	**0,2%**	**0,1%**	-117.454	-11,0%
EDUCA	**-0,4%**	**0,5%**	-7.546	-9,1%
SAUDE	**1,1%**	**-0,8%**	-214.940	-12,2%
SERVI	**-0,1%**	**-0,2%**	-22.951	-10,5%
TOTAL	**1,4%**[a]	**-1,46%**[b]	-7.275.940[c]	-12%[c]

Source: Own Elaboration

Notes: % prices not deflated; [a]inflation; [b]activity index; [c]variation of CO2 emissions

The effects on welfare of the environmental tax in combination with lump sum transfers, are a little better when analysing the equivalent variations of welfare in real terms. However, we can observe a variation of +0,2% in the non environmental real welfare which means a gain of +218 millions of Euros, while in GTR we verified a loss of -0,3% (less 327 millions of Euros). The environmental benefits increase welfare in +145,5 millions of Euros, a greater effect than the one the GTR provided to society. As a result of the previous partial effects, the social real welfare would experience, with the second reform, a gain of +364 million Euros, which represents an increase of +0,33%.

With reference to trade balance and energetic dependence towards other countries, we conclude that the sectors with greater improvements on trade balance with this reform are extraction of energy products, manufacture of machinery and manufacture of electric equipment. The sectors whose balance worsens are refined petroleum products, transports and manufacture of textiles.

In relation to net exports of energy sectors, the effects are similar to the ones of the GTR with SSC reductions. In this case, the energy balance improves in +96 million Euros. With this reform, the economy imports (net of exports) less -1,2 CO_2 million tons (this represents less -7,2% of the net imported emissions on benchmark).

5.4 Sensitivity Analysis of results

The intention of this section is to test the sensitivity of the results obtained by the model to changes in the simulated policy.

We thought it was important to evaluate the GTR effects with different values of the environmental tax. So, we repeated the two simulations using a tax of 10 € and a tax of 40€.

The first value was chosen because it leads to a reduction of emissions close to 5%, which was the estimated deficit of Portugal for the period 2008-2012, to comply with the Kyoto target[51]. Presently it is estimated that this deficit will be lower or even will not exist at the end of the period, mainly due to the economic crisis. On the other side, this is a

[51] See Comissão para as Alterações Climáticas (2009) Memorando - Estado de Cumprimento do Protocolo de Quioto, in http://www.cumprirquioto.pt/documents/List.action

lower band for CO2 prices in 2008-2012[2], which are also being affected by the economic crisis.

It was also important to simulate a tax of 40€, to evaluate the effects of a more restrictive environmental policy, leading to an emission level near to the European goal to 2020 (21% of reduction comparing to 2005). Furthermore, this value could reflect the reality of the CO2 market when the economic crisis is surpassed.

In Table 10 we can see the interval of variations for these values of environmental tax in terms of employment, wages, prices, GDP and CO2 emission reductions.

Table 10 - Sensitivity of main results with different values for the environmental tax

	Simulated Scenarios					
	1	**2**	**3**	**4**	**5**	**6**
Employment	0,8%	0,8%	1,5%	-0,3%	-0,5%	-0,8%
Wages	1,5%	2,9%	5,3%	-0,4%	-0,6%	-1,1%
Prices	0,7%	1,3%	2,5%	0,7%	1,4%	2,7%
Real Wages	0,8%	1,6%	2,7%	-1,1%	-2,0%	-3,7%
GDP pa	0,5%	0,9%	1,6%	0,1%	0,4%	0,7%
GDP bp	-0,4%	-0,7%	-1,4%	-0,7%	-1,2%	-2,2%
real GDP pa	-0,2%	-0,4%	-0,9%	-0,5%	-1,0%	-1,9%
real GDP bp	-1,1%	-2,0%	-3,8%	-1,4%	-2,6%	-4,8%
CO2 emissions	-6,4%	-11,6%	-19,6%	-6,6%	-12,0%	-20,2%

Notes:

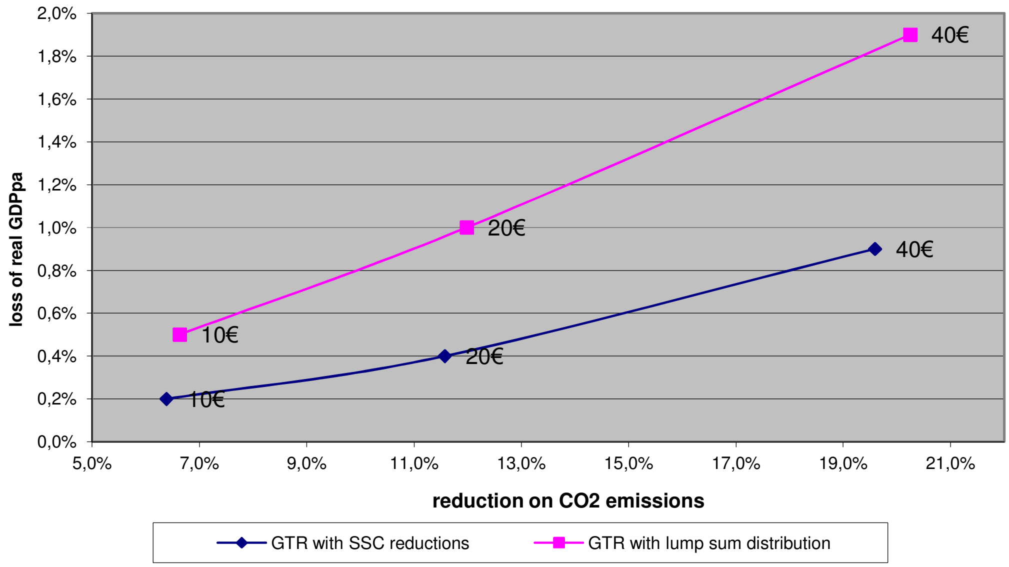
simulated scenarios	1	GTR with CSS reduction and environmental tax of 10€
	2	GTR with CSS reduction and environmental tax of 20€
	3	GTR with CSS reduction and environmental tax of 40€
	4	GTR with lump sum transfers and environmental tax of 10€
	5	GTR with lump sum transfers and environmental tax of 20€
	6	GTR with lump sum transfers and environmental tax of 40€

Source: Own Elaboration

This range of values for the environmental tax allows us to evaluate the marginal cost evolution in terms of GDPpa, as we raise the tax. As can be seen in Figure 9, the curve of economic cost of the different simulated GTR is a convex curve. That means that, when we raise the environmental goal, the economic cost raise in a bigger proportion. The same effect can be seen in other variables, like prices and employment.

[2] Accordingly to data published in the European Carbon Market Monthly Bulletin by Caissê des Dépôts.

Figure 9 - Cost of GTR with different values of environmental tax



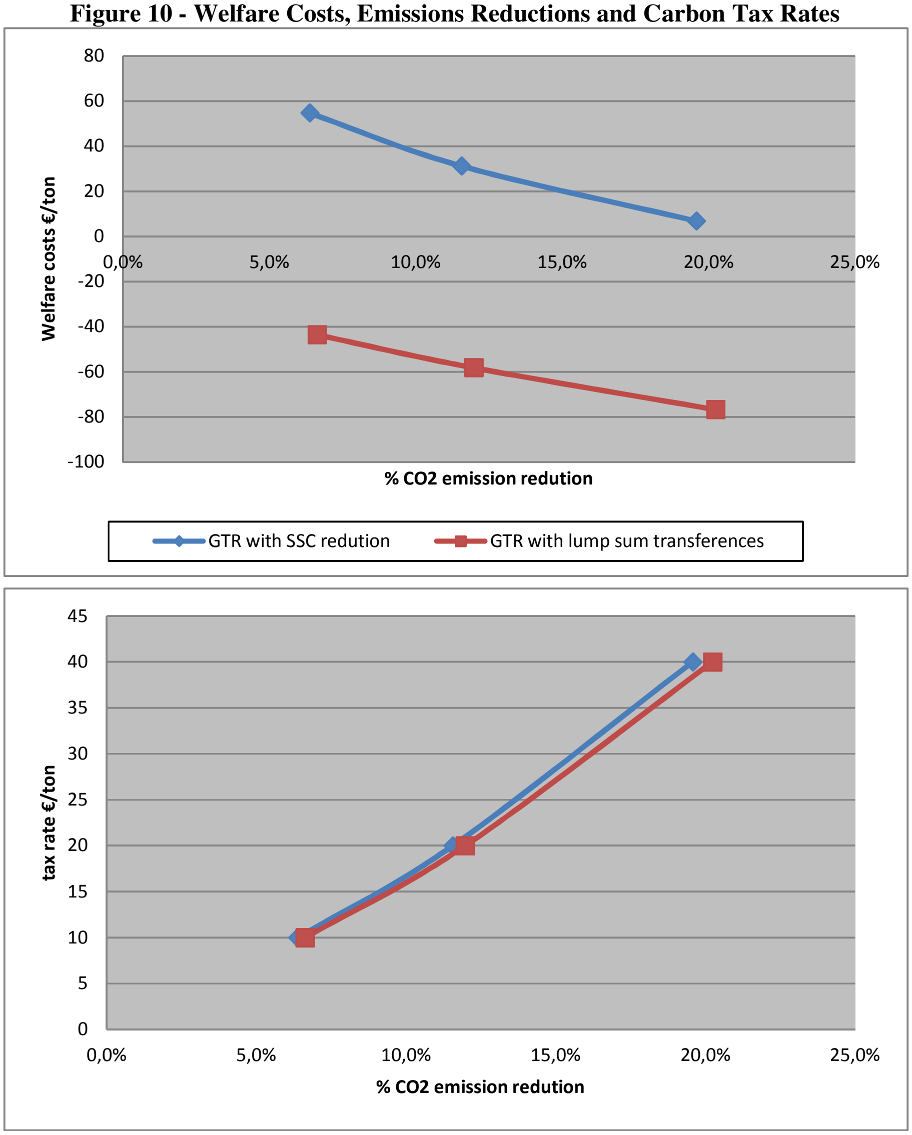
Source: Own Elaboration

Figure 10 (lower graph) shows us the results in CO2 emission reduction as we raise the tax. As we can see, the results are very similar whether the revenues are used to lower SSC or returned as lump sum transfers. The convex curves reveal that, for bigger environmental goals, the tax have to rise more than proportionally, which causes bigger losses in GDP as we saw in Figure 9.

On the other side, the different use for the revenues has different effects on welfare as shown by Figure 10 (upper graph). The blue line shows that with SSC reductions we have decreasing welfare costs, i.e., as we reduce emissions more, the welfare cost is shrinking. The red line shows that with lump sum transfers we have welfare improvements (negative costs) that are increasing with the reduction of CO2.

From these we can conclude that the bigger the environmental goal, the bigger the costs for the economy, but the lesser are the welfare costs. We remind that welfare, in our model, has an environmental and a non environmental component. So, as we reduce emissions, there are economic costs that negatively affect welfare, but the environmental components become stronger and compensate a bigger proportion of these costs.

Figure 10 - Welfare Costs, Emissions Reductions and Carbon Tax Rates



Source: Own Elaboration

Note: Upper graph shows welfare costs of emission reductions. Lower graph shows the carbon taxes required for particular emissions reductions.

5.5 Conclusions and policy implications

The objectives of this chapter were to evaluate and present the economic effects of a GTR implemented in the Portuguese economy. Two kind of reforms where studied: first, a reform with introduction of an environmental tax on fossil fuel consumption and recycling of revenues through SSC reduction; and second, the same reform but with recycling of revenues through lump sum transfers. We also made a sensibility analysis using three different values for the environmental tax.

The environmental improvement is slightly bigger in the simulation with lump sum transfers, because this is more focused in the environmental goal. The electricity sector is the one that reduces more emissions in both reforms, perhaps because it has more possibilities of substitution of energy inputs used in its production and also because it is the most important consumer of fossil fuels.

As the tax increases, the effects are more positive for the employment level in the reform that reduces the SSC, whereas they are worse in the reform that makes lump sum transfers.

GTR has more positive effects in national production than the reform with lump sum transfers. The Activity Index for the first one is of 99,24% and 98,54% for the second one. So, GTR minimizes the costs that producers should assume due to emissions reductions. For real GDPbp the results are worse than for real GDPpa[52].

The sectors most damaged in production and prices are, as expected, the more energy intensive sectors. In terms of trade balance, we have a reduction of the energy bill in both kinds of simulation.

We verify that a GTR produces an increasing improvement of real wages which is counterbalanced with a simultaneous increase on prices, but still the economy could account for an increase of the consumer purchase power. In the second simulation, the increase in prices is similar, but there is a reduction on nominal and real wages.

We must conclude therefore that, with a GTR with reduction in the social contributions due by employers, there is not a "double dividend", following the definitions presented in chapter one. We only can say that this policy lead to an "employment double dividend", since it has important environmental effects and improve employment. But this reform would have a cost in economic terms, decreasing the real value added generated by the economy by a 0,4%, leading to a redistribution of the economic activity between the different sectors, with positive but moderate effects on the price index (+1,3%) and no significant welfare effects.

[52]Other studies present simulations that don't differentiate between these two variables. We presume that the variable considered for their conclusions is GDPpa. In our opinion real GDPpa could better reflect welfare and real income.

With a GTR with lump sum transfers there is a "double dividend" following the "weak" definition of Goulder, the definition of the public finance approach, and the definition of the environmental approach (see chapter one). Through Gimenez and Rodriguez definition we only obtain the first dividend but not the second one. In this reform we obtain environmental and welfare gains, but have an economic cost of -1%, measured in real GDPpa, with positive but moderate effects on the price index (+1,4%).

It is important to notice that these simulations present very modest results concerning job creation, variation in GDP, welfare and prices, because, as was already pointed, full employment is assumed as benchmark and, in reality, Portugal has a rate of unemployment clearly different from zero. On the other hand, the model does not consider the possibility of adaptation to the tax through technology change and through measures to improve efficiency. Therefore, the scenario is more pessimistic in terms of tax induced employment variation. Beyond this, we consider a unilateral application of the tax by Portugal. A multilateral cooperation upon a GTR by several related countries would have more positive effects (Carraro and Galleoti, 1997; Bosello et al., 1998).

Anyway, these simulations showed us that it is possible to comply with the Kyoto targets without damaging employment and social welfare.

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6. Sectoral and regional impacts of the European Carbon Market in Portugal

6.1 Introduction

In accordance with the Kyoto Protocol, signed in 1997, the EU has pledged to reduce the emissions of GHG. The EU ETS was established to that effect by Directive 2003/87/CE. An ETS (emission permit system) is a pollution-control instrument based on requiring pollution sources to hold transferable permits. The regulator issues the desired number of permits and each source designs its own compliance strategy, including sale or purchase of allowances and pollution abatement. The incentives created by this system ensure that each source has enough flexibility to minimize its compliance costs and, as a consequence, the policymaker's environmental goals are achieved cost-effectively, i.e., at the lowest possible cost for the whole economy.

In spite of the desirable theoretical properties of emission permit schemes, the nature of the EU ETS raises a few efficiency and fairness concerns. Cost-effectiveness of any environmental regulation requires a full coverage of emitters, especially when non-subject sectors present lower abatement costs (see Böhringer et al, 2006). Also, any unequal treatment of sectors generates distributional consequences. For instance, Kettner et al (2008, 2010) show that the power and heat sector has been the only net allowance buyer and discuss whether allocations have favoured large installations relative to smaller ones. In defence of the EU ETS design, we must argue that a market limited to main emitters is appealing, mainly due to a reduction of administrative and compliance costs. Furthermore, there is no evidence of market power, which, if it existed, would diminish trading efficiency (Convery and Redmond, 2007). For a more complete discussion, Convery (2009) reviews the literature on emissions trading in Europe.

Another problem is associated with the free allocation of pollution permits by most governments, despite the empirical evidence on the superiority of auctioning. In the EU ETS, governments could auction up to 5% of allowances in phase I (2005-2007) and up to 10% in phase II (2008-2012). In phase I, only four out of 25 Member States used auctions at all, and in only one case were auctions fully employed to the 5% limit (see Hepburn et al (2006) and Ellerman and Buchner (2007)). Cramton and Kerr (2002) note that auctioning "allows reduced tax distortions, provides more flexibility in distribution of costs, provides greater incentives for innovation, and reduces the need for politically contentious arguments over the allocation of rents." This is in line with the conclusions of the literature on revenue recycling through distortionary tax reduction (Parry et al. 1999; Fullerton and Metcalf 2001). Environmental instruments aim to correct pre-existing market distortions; therefore, when they are used to raise revenue (such as with environmental taxes or auctioned permits), other taxes which carry deadweight losses (such as labour or income taxes) can be reduced. This type of "green" fiscal reform could thus allow a reduction of the total tax burden in the economy.

Additionally, since climate is affected by the global stock of GHG, the possibility that emissions rise outside the EU because of its stricter policy (i.e. carbon leakage) can seriously hamper the environmental effectiveness of EU efforts. The problem is more acute for tradable sectors that are GHG-intensive, such as iron and steel or cement. However, Reinaud (2008) concludes that there is no significant evidence for carbon leakage due to the EU ETS in the first three years of the scheme. Likewise, EC (2010) states that the expected ETS-related reductions in production for covered industries until 2020 are very small, albeit this is partly due to the favourable treatment such industries have received.

A final point is that regulation falls on installations that in turn are anchored in a physical territory. The EU ETS does not have an explicit regional dimension, which is understandable given the global nature of the GHG problem. Nonetheless, the specialization of the different regions in the production of different goods and services can lead to different economic impacts of the carbon market from a regional point of view. If there is no proportionality between the regional share of affected installations and population, value added or employment, we can expect important distributional effects between regions, in Europe and even within countries. The European Commission recognizes the importance of enhancing emission reduction without jeopardizing growth in different areas of Europe, and refers cohesion policy, which has a strong regional focus, as an important instrument in this regard (EC, 2010). Hence it is important to study both the sectoral and regional impact of the EU ETS. There is some research on the distributional consequences of financial flows among countries and firms as a consequence of the EU ETS (see for instance Kettner et al 2010, Trotignon and Delbosc, 2008 and the references therein). However, there is usually no data providing economic context of such flows and little attention has been paid to the regional impacts inside countries in the literature, with the exception of Spain (Rodriguez and del Rio, 2008).

The contribution of this chapter is to focus on the Portuguese case, analysing in detail both regional and sectoral EU ETS economic impacts. To this goal we use data from 2005 to 2009 for Portuguese installations covered by the EU ETS. More important, the main novelty of this piece of research is to conduct the analysis by pooling together data from the Community Transaction Log database and installations financial data from the "Iberian Balance Sheet Analysis System" (SABI) database for the first four years (it is created and produced jointly by INFORMA D&B and Bureau Van Dijk). The regions are shown according to the European NUTS III classification, consisting of 28 regions in continental Portugal and the Autonomous Regions of Madeira and Azores.

The data reveal that: i) Portuguese carbon emissions allowances are extremely concentrated in a small number of installations; ii) the thermoelectric sector was the only one that had significant negative balances; iii) other sectors appear to have benefited from EU ETS participation, some significantly so; iv) a limited number of regions show a high concentration of regulated emissions, surpluses and deficits. Those results, together with the fact that about 60% of national emissions remain unregulated by the EU ETS, highlight the necessity of considering the full distributive impacts when analysing policy measures.

The chapter is made up of eight sections, including this introduction. Section 2 describes the EU ETS, whereas Section 3 focuses on the first Portuguese National Allocation Plan (NAP). Sections 4 and 5 analyze the sectoral and regional effects of the EU ETS in Portugal, respectively. The Portuguese NAP for the second period, 2008-2012, is described in Section 6. Finally, some policy implications and the main conclusions are set out in Sections 7 and 8, respectively.

6.2. The European Union Emission Trading System

The EU ETS was established to that effect by Directive 2003/87/CE. It is based on six fundamental principles: i) it is a "cap-and-trade" system (an overall cap is set, defining the maximum amount of emissions, and sources can buy or sell allowances on the open market at European level); ii) it is focused on CO2 from large industrial emitters; iii) implementation is taking place in two phases (2005-2007 and 2008-2012) with periodic reviews; iv) emission allowances are decided within national allocation plans; v) it includes a strong compliance framework; vi) the market is EU-wide but taps emission reduction opportunities in the rest of the world through the use of the Clean Development Mechanism and Joint Implementation, and it also provides links with compatible systems in third countries.

The installations covered by the EU ETS initially received allowances for free from each EU Member State's government, in what is known as "grandfathering". However, since unused permits[53] can be sold, installations are stimulated to invest in emissions reduction even when they are under their "cap" (the grandfathered allocated permits).

Until now, each Member State was able to decide the sum of permits to attribute to the installations regulated by the Directive, following criteria provided by the European Commission. In the two initial phases, a limited number of sectors was included: energy activities (combustion, refineries, coke ovens); iron and steel (production and processing); mineral industries (cement, glass, ceramic products); and pulp and paper. It should be noted that the emissions of the installations covered by the market represent approximately 40% of the total CO_2 EU emissions.

In April 2009, the new energy-climate package was approved[54]. This includes a revision of the EU ETS (Directive 2009/29/EC) which contemplates: (i) an EU-wide target for GHG industrial *emissions* to achieve a 21% decrease in 2020 compared to 2005 emissions[55]; (ii) an extension of the EU ETS to include two other GHG, nitrous oxide and perfluorocarbons, and to cover other sectors, namely aviation and the petrochemical, ammonia and aluminium sectors; (iii) a greater share

[53] Carbon permits in the EU ETS are named European Union Allowances (EUA) and each covers one ton of carbon. Henceforth we will use the word "permit" when referring to EUA.
[54] See http://ec.europa.eu/environment/climat/climate_action.htm
[55] And 30% compared to 1990 emissions (see European Commission (2007a))

(above 50 %) of auctioned permits, albeit differentiated among sectors; (iv) an opt-out possibility for small installations, emitting below 25 000 ton CO_2/year, which show alternative reduction measures. These changes will enter into force in January 2013. The package also contains other provisions, such as national binding targets for renewable-energy use and for non-ETS sectors, in order to reach, respectively, a share of renewables in final energy demand of 20% and an average reduction of 10% in these sectors' GHG emissions, by 2020.

In the first year of trading (2005) 362 Mt (million tonnes) of CO_2 were traded on the market for a sum of €7,2 billion, as well as a large number of futures and options (Point Carbon (2006)). The price of permits increased, more or less steadily, to its peak level, in April 2006, of about €30 per tonne CO_2, but fell in May 2006 to under €10 on news that overall emission caps were so generous that, in many countries, there was no need to reduce emissions. The trading price collapsed to 1,2€ in March 2007, declining further to €0,10 in September 2007. Verified emissions, on the other hand, grew in the first phase of the scheme, although by less than GDP. For the countries for which data is available (all 27 member states except Romania, Bulgaria and Malta), emissions increased by 1,9% between 2005 and 2007 (European Commission, 2008).

Phase I is widely believed to have been over allocated. Note that countries are said to be short (long) if they had emissions greater (smaller) than their allocation, so that they are potential buyers (sellers) of allowances from (to) other countries, in order to achieve compliance. The same terminology can be used for sectors. The number of permits distributed to installations in 2005 exceeded those installations' emissions by about 176 Mt or 7,7 % of the total EU cap (see Table 11).

Only 5 countries were in a short position in Phase I, which could imply that few additional overall emission reductions have been achieved. However, Ellerman and Buchner (2008) emphasize that simply comparing emissions with the cap does not take into account abatement brought about by ETS participation. In their analysis, they compare actual emissions with business-as-usual scenarios, to show that abatement might actually explain a significant part of the overall Phase I surplus. At any rate, caps for the second trading period have been lowered 9,5% for the EU as a whole.

Some of the EU15 member states had a net "short" position in 2005, notably Spain, which had the highest deficit (close to 5%). All the EU10 countries, on the other hand, were "long", often significantly, as in the case of the Baltic countries.

Table 11 - Caps by Member State in 1st and 2nd period of EU ETS (quantities in Mt CO2)

Member State	*1st period cap*	*2005 verified emissions*	*Deficit (-) or surplus (+) in %*	*Cap allowed 2008-2012*
Austria	33	33,4	-1,2%	30,7
Belgium	62,1	55,58	10,5%	58,5
Bulgaria	42,3	40,6	4,0%	42,3
Cyprus	5,7	5,1	10,5%	5,48
Czech Rep.	97,6	82,5	15,5%	86,8
Denmark	33,5	26,5	20,9%	24,5
Estonia	19	12,62	33,6%	12,72
Finland	45,5	33,1	27,3%	37,6
France	156,5	131,3	16,1%	132,8
Germany	499	474	5,0%	453,1
Greece	74,4	71,3	4,2%	69,1
Hungary	31,3	26	16,9%	26,9
Ireland	22,3	22,4	-0,4%	22,3
Italy	223,1	225,5	-1,1%	195,8
Latvia	4,6	2,9	37,0%	3,43
Lithuania	12,3	6,6	46,3%	8,8
Luxembourg	3,4	2,6	23,5%	2,5
Malta	2,9	1,98	31,7%	2,1
Netherlands	95,3	80,35	15,7%	85,8
Poland	239,1	203,1	15,1%	208,5
Portugal	38,9	36,4	6,4%	34,8
Romania	74,8	70,8	5,3%	75,9
Slovakia	30,5	25,2	17,4%	30,9
Slovenia	8,8	8,7	1,1%	8,3
Spain	174,4	182,9	-4,9%	152,3
Sweden	22,9	19,3	15,7%	22,8
UK	245,3	242,4	1,2%	246,2
Total	**2298,5**	**2122,16**	**7,7%**	**2080,93**

Source: European Commission (2007b); Additional information on which installations are included is given in the source.

Ellerman and Buchner (2007) discuss the disparities among countries for 2005, presenting the gross positions for each one as well as the net ones. Kettner et al (2010) provide a similar analysis for the three years of the first period. Both papers note that the member states which comprise a large part of the potential demand are also important suppliers, indicating that many trades were among installations within each country. They also provide a brief sectoral analysis. It is clear that for the EU as a whole, the Power & Heat sector was the only one to have a short position, while the other industrial sectors were all long, often by large percentages (around 20% for Ceramic, Iron, Steel & Coke, and Pulp & Paper). The underlying reasons for this uneven distribution of permits among sectors appear to have been: the fear of loss of competitiveness for GHG-intensive tradable sectors, carbon leakage and also the cheaper abatement options available to the power sector. As a result, the NAPs were generous in the number of allowances allocated except for the Power & Heat sector. Unsurprisingly, this sector, which makes up around 60% of EU ETS emissions, represented in 2005 nearly 90% of potential permit demand. It also accounted for some 50% of the potential supply, thus justifying most of the market's activity.

6.3 The first Portuguese National Allocation Plan

The target established by the Directive for Portugal was that, during the Kyoto compliance period (2008-2012), mean emissions cannot exceed a 27% increase over the emission levels of 1990.

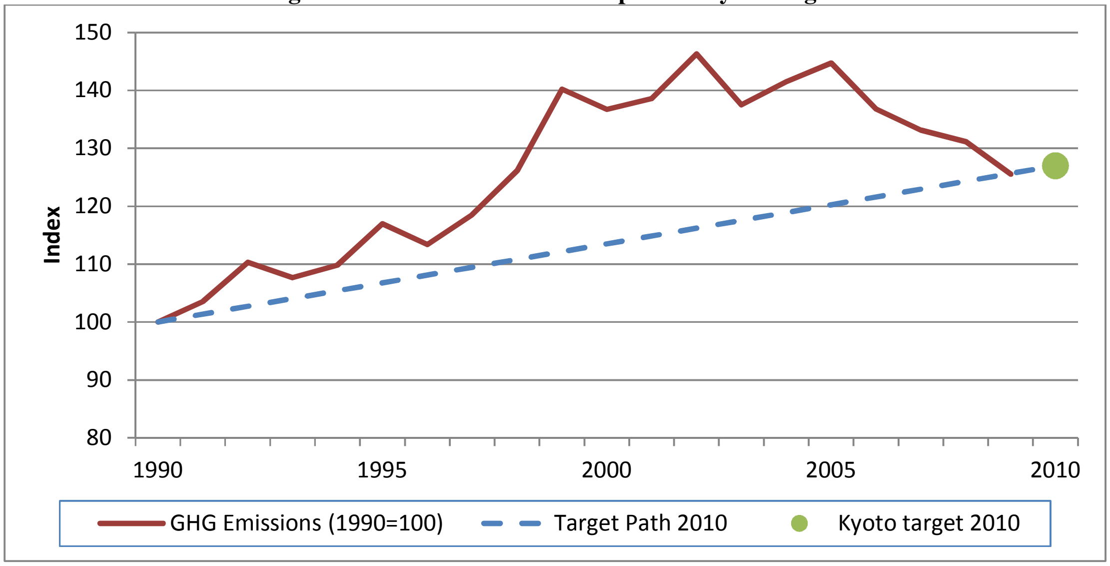
Figure 11 illustrates the evolution of emissions until 2009 and the linear path to achieving the target in 2010, excluding land use change and forestry (LULUCF). The latest official estimates say the GHG emissions in 2009 were about 74,6 MT CO_2e, an increment of 26% compared with the 1990 levels[56].

The value of these emissions is lower than the predicted in previous years, due to the significant inflexion in emission path during the last two years, explained by the economic crisis but also by the efficiency gains of the economy (lowering the carbon intensity of national product).

As we can also see in Figure 11, emissions show significant annual variability, mainly due to the fluctuations in hydroelectric power generation, that are caused primarily by precipitation variability, as discussed in Section 4.

[56] See Agência Portuguesa do Ambiente(2011).

Figure 11 - Emissions and linear path to Kyoto target



Source: Own elaboration using data from Agência Portuguesa do Ambiente

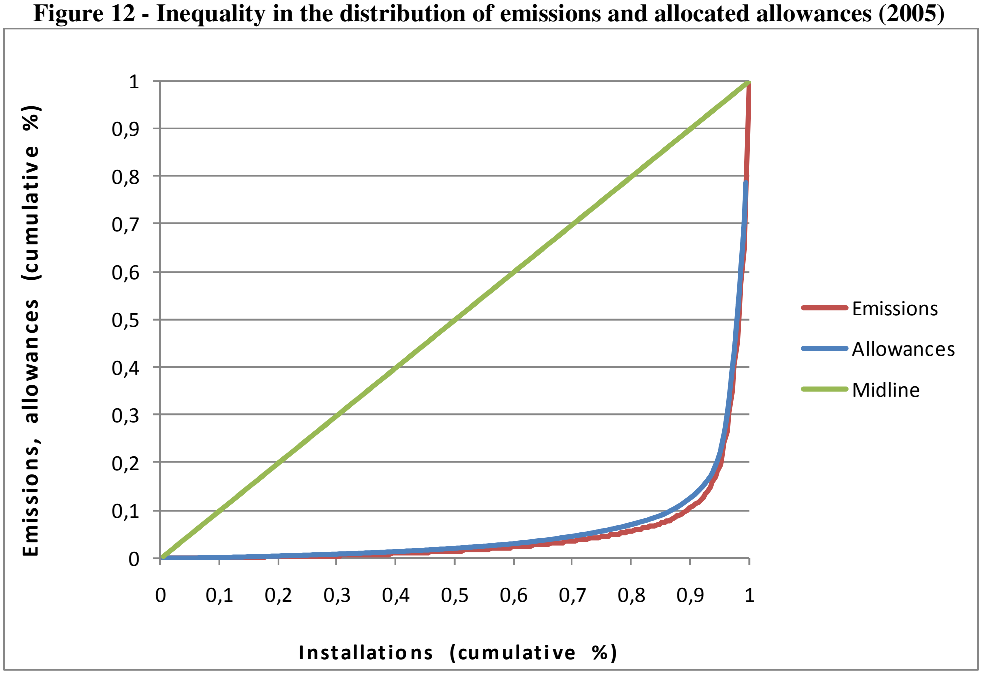
The first Portuguese NAP, covering the period 2005-2007, considered 38,9 Mt of CO_2 per year, of which 36,9 Mt for 244 industrial installations and the remainder left aside for new installations. Mostly, historical emissions were used to distribute allowances between sectors and installations. Exceptions were made for new installations and for the sectors of electricity generation and iron and steel, where historical data was seen as inappropriate, considering technological potential for emission reduction. Moreover, as in most other EU countries, benchmarking was not used (see Ellerman and Buchner, 2007).

The actual distribution of permits among the 244 installations covered by the EU ETS was based specifically on two criteria: (i) the historical emissions of each one, which had previously been used for the definition of the total permits assigned to each sector and (ii) combustion emissions assuming an "average fuel" for each activity sector. Individual assignments were given out based on the sum of adjusted combustion emissions with historical emissions. Finally, this sum was multiplied by a factor of global adjustment (equivalent to that used for the calculation of the emissions for each sector).

An undeniable characteristic of the first Portuguese NAP was the inclusion of a large number of small installations.

Figure 12 ranks the 244 Portuguese installations according to their allocated emissions and reveals the extreme inequality of their size. We can highlight from the permit allocation that 10% of installations have 90% of emissions permits. Also, two installations jointly have 31,5% of permits, and there are 163 installations classified as small (less than 25 000 tons of CO_2), which together account for less than 4% of emissions. Portuguese allowances are thus extremely concentrated. This is similar to findings for all EU countries, where Kettner et al (2008) conclude that the biggest 1,8% of installations account for 50% of emissions. Naturally, regions where these are located will bear a large percentage of the emission reduction effort.

Figure 12 - Inequality in the distribution of emissions and allocated allowances (2005)



Source: Own elaboration using data available in http://ec.europa.eu/environment/ets

6.4 Sectoral effects of the European Carbon Market in Portugal

Based on the final reports of the EU ETS for the years 2005, 2006 and 2007, we can identify sectors that were short and long and assess the potential monetary flows from allowance purchases or sales. Unfortunately this ex-post analysis does not provide any insight into the drivers of actual emissions for the firms. In particular, for “long” installations we do not have any information on abatement efforts nor on the associated costs, which would allow a fuller view of the net result of market participation.

Recall that the Portuguese NAP attributed the equivalent of 36,9 Mt of CO_2 for each year in the first period. Along this period, Portuguese installations had a surplus that could have provided revenues of approximately 10,4 M€, 58,8 M€ and 7,5 M€ for all installations. Table 12 shows the sectoral breakdown in terms of emissions and Table 13 the possible monetary flows. Positive values indicate potential income from allowance sales and not actual revenues, as it is unlikely that all surplus allowances were actually sold. Moreover, even if they had been, the net economic position from EU ETS participation would need to take into account transaction costs, which tend to be higher for smaller firms, and the abatement cost incurred, if any. Still, ETS data indicates that, in the first phase, fewer than 10% of Portuguese EUA expired worthless (Trotignon and Ellerman, 2008).

Table 12 - Emissions (in Mt) and Attributed Allowance Coverage (%) for 2005, 2006 and 2007

	2005		2006		2007	
Sectors	**CO_2**	**%**	**CO_2**	**%**	**CO_2**	**%**
Thermoelectric generation	21,91	96	18,67	112	16,42	128
Ceramic	0,87	134	0,81	143	0,88	132
Cement and lime	6,98	102	6,86	104	7,11	100
Cogeneration	2,06	121	2,06	121	2,22	112
Other Comb. Facilities	0,42	127	0,39	135	0,42	128
Iron and steel	0,22	140	0,24	130	0,23	132
Pulp and paper	0,31	115	0,31	117	0,31	115
Refineries	3,01	109	3,02	108	2,94	111
Glass	0,64	106	0,64	104	0,70	98
Total	**36,4**	**101**	**33,0**	**112**	**31,23**	**118**

Source: Own elaboration using the data available in http://ec.europa.eu/environment/ets.
Note: totals for 2006 exclude 3 installations which were removed, as there were problems with their emissions data.

Table 13 - Potential financial outcome of EU ETS transactions (in Million€) for 2005, 2006 and 2007

Sectors	2005 price 21,73€/ton	2006 price 15,14€/ton	2007 price 1,3€/ton
Thermoelectric generation	-20,50	34,85	6,00
Ceramic	6,47	5,24	0,37
Cement and lime	3,32	4,14	0,04
Cogeneration	9,26	6,49	0,36
Other Comb. Facilities	2,42	2,09	0,15
Iron and steel	1,92	1,09	0,10
Pulp and paper	1,05	0,80	0,06
Refineries	5,58	3,75	0,43
Glass	0,89	0,39	-0,02
Total	**10,40**	**58,82**	**7,48**

Source: Own elaboration using the data available in http://ec.europa.eu/environment/ets.
Notes: Prices are the weighted average prices of permits traded by European companies, calculated from the monthly average prices and the monthly volume of allowances (tons of CO2) interchanged in the European market, using the data in the ECM Monthly Bulletin published by Caissê des Dépôts (www.caissedesdepots.fr/missionclimat/).

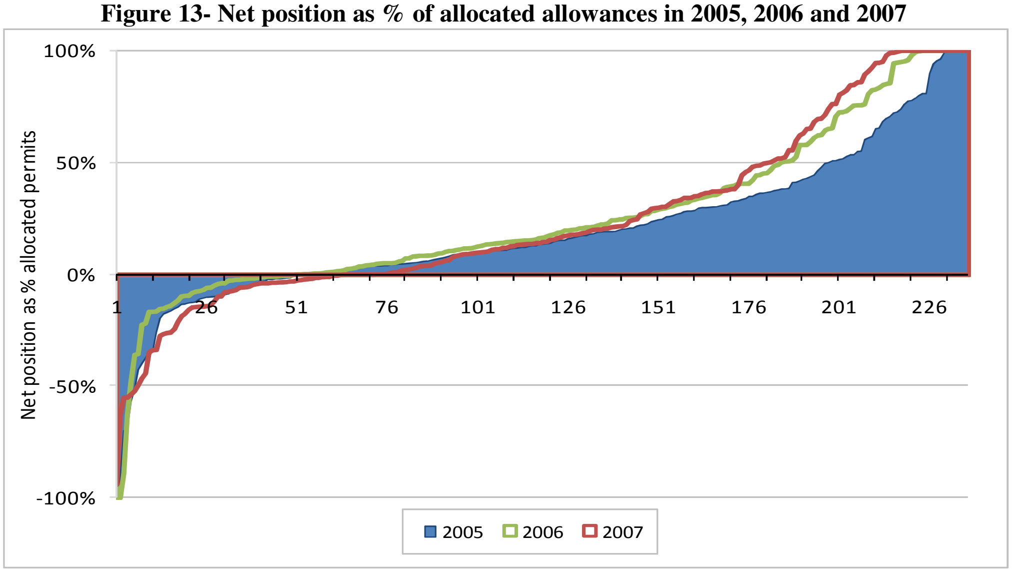
Thermoelectric plants have a negative balance in 2005, that is, they discharged more emissions than the allowances allocated to them (approximately one million tons of CO2 in excess). The assigned allowances in that year covered 96% of emissions, mainly due to a drought that reduced hydroelectricity generation, as discussed in section 6.4.1. There was also a small deficit for Glass in 2007. In the remaining sectors there was a surplus of emission allowances for all years, especially so for Ceramic, Iron and Steel, Other Combustion Facilities and Cogeneration. For comparison, at a European level, the sectors with larger surpluses were Pulp and Paper, Iron and Steel and Ceramic (Kettner et al 2010). We provide some analysis on the significance for each sector of the potential extra revenues and costs below.

One important advantage of microdata is that we can perform a detailed analysis of the potential outcome of the carbon market, with data for each installation.

Figure 13 shows the wide discrepancies in the net positions held by different installations. Obviously, these discrepancies reflect the interaction between allowance allocation, abatement activities, and general activity level. The right-hand tail in this figure, with positive 100% positions, refers to installations that had zero carbon emissions despite having positive allowance allocations. On the other hand, those with negative 100% positions represent installations that had to cover double their initial allocations[57]. In 2005 and 2006 around 20% of installations were short and 80% long. Nonetheless, the figure shows that there was a slight shift to the left side, accounting to more positive positions in 2006. On the contrary, in 2007 there was a slight shift to the right plus a slight rotation in such a way that a few more installations were short but those that were long were more so. For the same period, in the EU around 27% of installations were short (Kettner et al 2008).

In order to assess the economic implications of these positions for each sector's installations, we use the SABI database. It contains general information and, more important for our purposes, the financial accounts, for a large number of Iberian firms. We were able to get financial data for 80% of the EU ETS installations, representing approximately 59% of emissions for 2005 and 2006 (about 62% for 2007). The representativeness is even greater (in most sectors close to 100%) if we exclude from calculations Thermoelectric Generation (coverage for this sector is around 34%).

Figure 13- Net position as % of allocated allowances in 2005, 2006 and 2007



Source: Own elaboration using data available in http://ec.europa.eu/environment/ets

Table 19 in the Appendix includes detailed information about the sectoral coverage of emissions for each year. Some interesting conclusions can be presented regarding the possible significance of EU ETS participation in

[57] Each year had only one installation (not the same one) with a negative position lower than -100%. These were not included in the figure to minimize scale distortions.

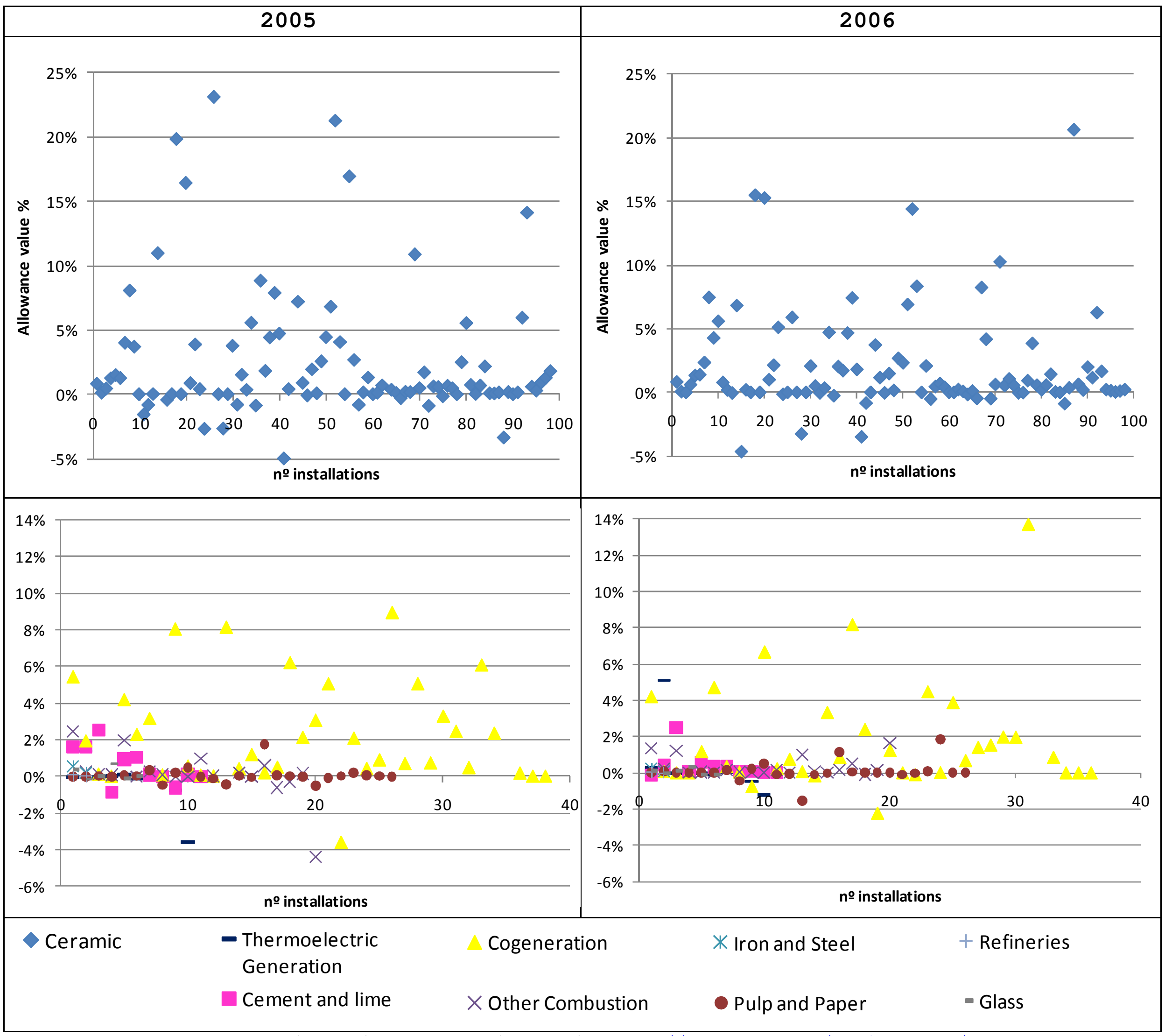
terms of financial accounts. We calculated potential revenue from allowance sales (or cost from allowance purchases) for each installation, using average annual allowance prices as explained in Table 13, as a percentage of that installation's operational revenues. The results are presented in
Figure 14 for 2005 and 2006. Results for 2007 are not shown since the low prices made potential ETS flows much lower as compared to costs/revenues. Ceramic is shown separately as it contains a much larger number of installations than other sectors and it has generally higher values (note the difference in scale).

Clearly, some installations may have generated a significant monetary inflow from EU ETS participation, especially in the Ceramic sector where quite a few had the possibility of making allowance sales above 5% of their operational revenues. However, these results should be viewed with caution, in light of possible transaction cost burdens, since the Ceramic sector is characterized by a large number of small installations. Again, we do not consider possible abatement costs. Among the other sectors, Cogeneration was the biggest potential beneficiary, with many installations earning an allowance return between 2 and 10% of operational revenues. It should also be noted that the proportion of potential revenues from allowance sales was generally higher in 2005, despite the slightly worse volume positions of firms, shown in
Figure 13. The price effect thus seems to have been paramount.

It is interesting to split this type of analysis between big and small emitters. We use as a criterion the Directive 2009/29/EC where installations under 25 000 tons CO_2/year are classified as small emitters. Considering all sectors, coverage values tend to be higher for small emitters than for large ones (266% against 142% for 2005-2006 and 199% against 109% for 2007). However, this would be expected given that the sectors that are dominated by large emitters have generally lower levels of coverage (this is true for Thermoelectric, Cement and Lime, Refineries and Glass, although Iron and Steel is an exception), and the one sector that is dominated by small emitters (Ceramic) consistently shows the most favourable coverage values. For those sectors where small and large emitters are both relevant (Cogeneration, Other Combustion Facilities, Pulp and paper),

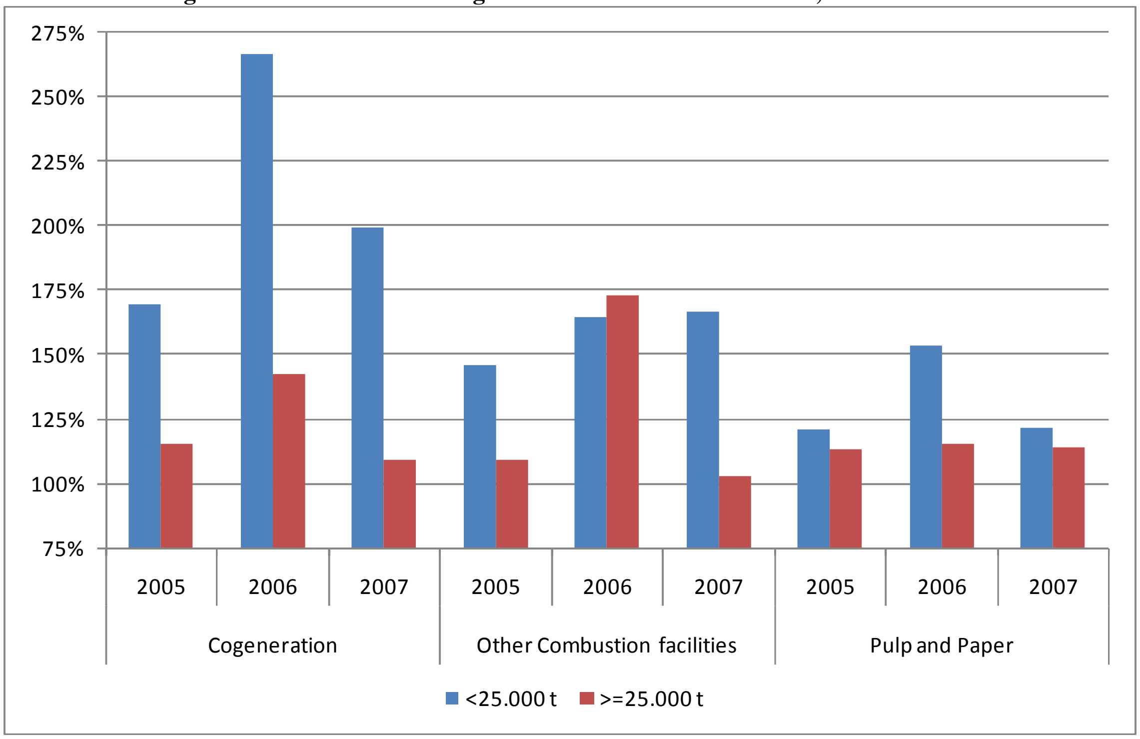
Figure 15 presents coverage levels for 2005 to 2007. From the data it is easy to appreciate that surpluses of allowances over emissions are systematically larger for small emitters, even within these sectors. There may be different reasons to explain this result, such as the lack of data to accurately allocate the right number of allowances to smaller emitters, a deliberate over allocation policy in favour of smaller emitters, or more intensive abatement actions by smaller emitters. Nonetheless, such analysis is beyond of the scope of this research.

Figure 14 - Potential Allowance Sales (Purchases) as % of Operational Revenue in 2005 and 2006 respectively for Ceramic and the other sectors



Source: Own elaboration using data available in http://ec.europa.eu/environment/ets and SABI data.
Note: All installations with zero emissions were removed from the sample for this figure, as well as a few outliers (4 with strongly positive permit revenues in 2005 and 1 in 2006).

Figure 15 - Allowance coverage for sectors with a mix of sizes, 2005-2007



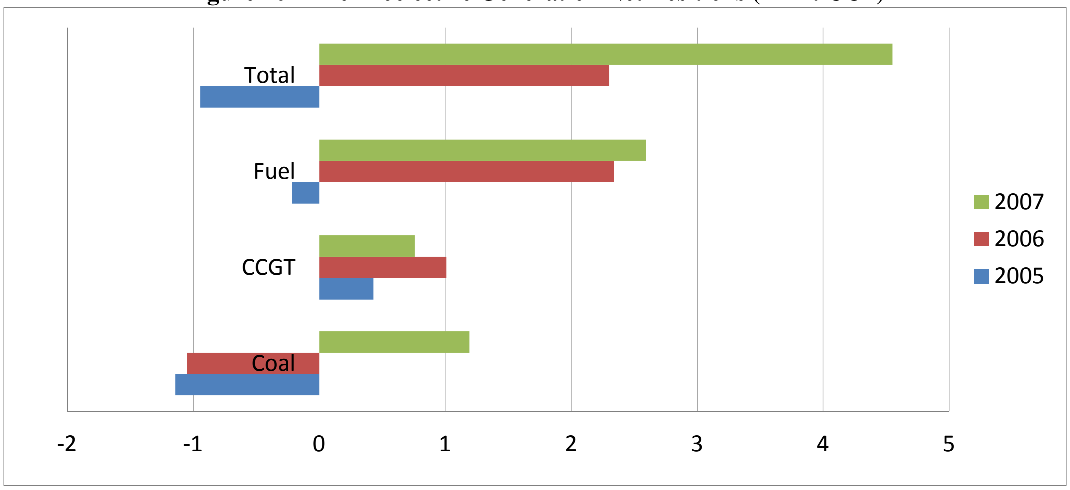
Source: own calculations

6.4.1 Thermoelectric Generation Sector

The thermoelectric generation sector deserves a closer analysis because of the bigger effort required of it, the volume of emissions it produces, and also the variability of emissions it shows in Portugal, depending on the weather patterns that affect hydroelectric production. InFigure 16 we show the net positions for 2005, 2006 and 2007 of the thermoelectric sector, divided into the subsectors of Fuel, Combined Cycle Gas Turbine (CCGT), and Coal. Other subsectors (Biomass and Gasoil) are not shown in the Figure due to their small size.

Overall, in Phase I the Thermoelectric sector had a net surplus of almost 6Mt CO2 (9% of allowances received), but there were relevant differences among years and subsectors. In 2005, the only "long" facilities were the ones using CCGT. The strong deficit shown by coal facilities and to a lesser extent, fuel facilities, meant that the sector as a whole presented a deficit. On the contrary, in 2006 this sector had a surplus even if coal facilities continued to show a negative balance, whereas all subsectors had surpluses in 2007.

Figure 16 - Thermoelectric Generation Net Positions (in Mt CO2)



Source: Own elaboration using data from http://www.dgge.pt/

To understand what happened in the period, we need to look at weather factors. The deficit in 2005 can largely be explained by that year's drought. It should be noted that renewable energy sources in Portugal, of which hydroelectric production is the largest by far (over 60% of installed capacity), normally account for a significant part of electricity consumption (between 20% and 40%). In 2005, that value was only 19,2%, with hydropower generation less than half its average value (the hydraulic index for the year was 0,42, which means that it rained 58% less than in an average hydrologic year). 2006, on the other hand, was an average hydrological year, and hydro production was 124% higher than in 2005. In contrast, 2007 was drier but renewable energy production still increased by 2%, since the slight decrease in hydro was more than offset by the growth in wind power generation. Interestingly, the large sectoral emissions reduction between 2006 and 2007 (-12% fewer emissions with only a -3,6% drop in electricity generation) cannot be fully explained by this factor, indicating that there were efficiency gains during the period.[58]

We end this section by noting that wide variations in emissions (hence in allowance transactions) should be expected for the power sector whenever

[58] Data is from http://www.dgge.pt/

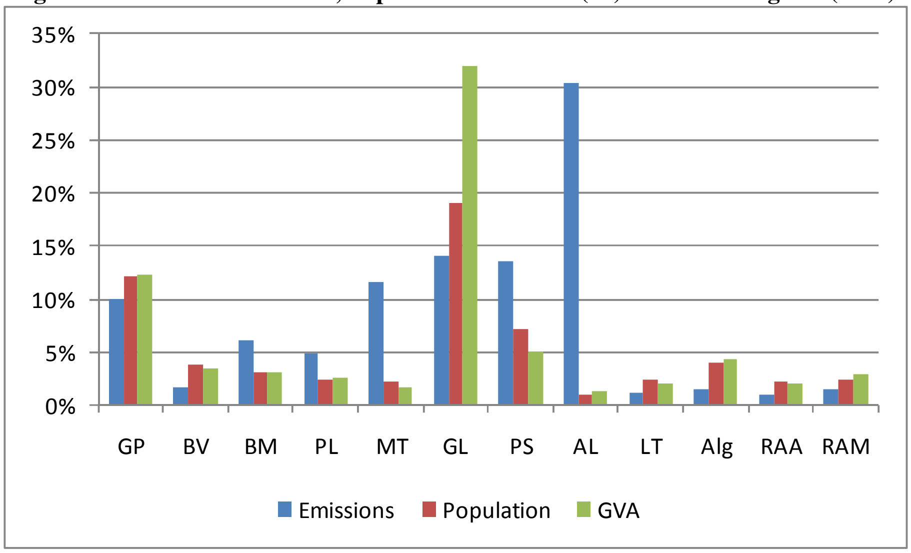
renewable sources, especially hydroelectricity, face large variability. For example, Ellerman and Buchner (2007) note that emissions also fluctuate greatly in Denmark, Sweden and Norway, depending on hydroelectricity production in the two latter countries. The effect may or may not show up in the allowance prices, depending on weather conditions throughout Europe. Although a couple of studies have looked at the effects of weather on allowance prices (Mansanet-Bataller et al (2007), Alberola et al (2008)), they focus on temperatures, which only drive demand, and not precipitation, which may also affect supply.

6.5 Regional effects of the European carbon market in Portugal

As noted in the Introduction, not much research has looked at the possible impact of EU ETS in regional terms in spite of the dissimilar impacts that can be expected among regions due to their specialization patterns in the production of goods and services. The European Commission recognizes the importance of enhancing emission reduction without jeopardizing growth in different areas of Europe, and refers cohesion policy, which has a strong regional focus, as an important instrument in this regard (EC, 2010). There are 30 NUTS III regions in Portugal, of which 5 have no registered emissions for any year and 13 have very low emission levels, of less than 1% of national emissions. The remaining 12 regions consistently account for around 97% of emissions. Figure 17 shows the relative weight of each one of these 12 regions in terms of emissions, population and Gross Value Added (GVA) for 2005 (values do not change much for different years).

There are relevant asymmetries in the contribution of each region to the different variables. In particular, we can see that the two largest metropolitan areas (Grande Porto (GP) and Grande Lisboa (GL)) have the largest shares of population and GVA, yet account for a smaller share of emissions. Also noticeable are the regions whose relative level of emissions largely exceeds their contribution to the GVA, such as Peninsula de Setúbal (PS), Médio Tejo (MT) and the most evident case, Alentejo Litoral (AL), which contributes with 32,1% to national emissions and only 1,3% to GVA. We can also see (and confirm with Table 18 in the Appendix) that 80% of regulated emissions come from only 5 regions, which together represent 52% of national GVA. As in the sectoral analysis, there is a high concentration of regulated emissions in a limited number of regions which are those where most industry is located.

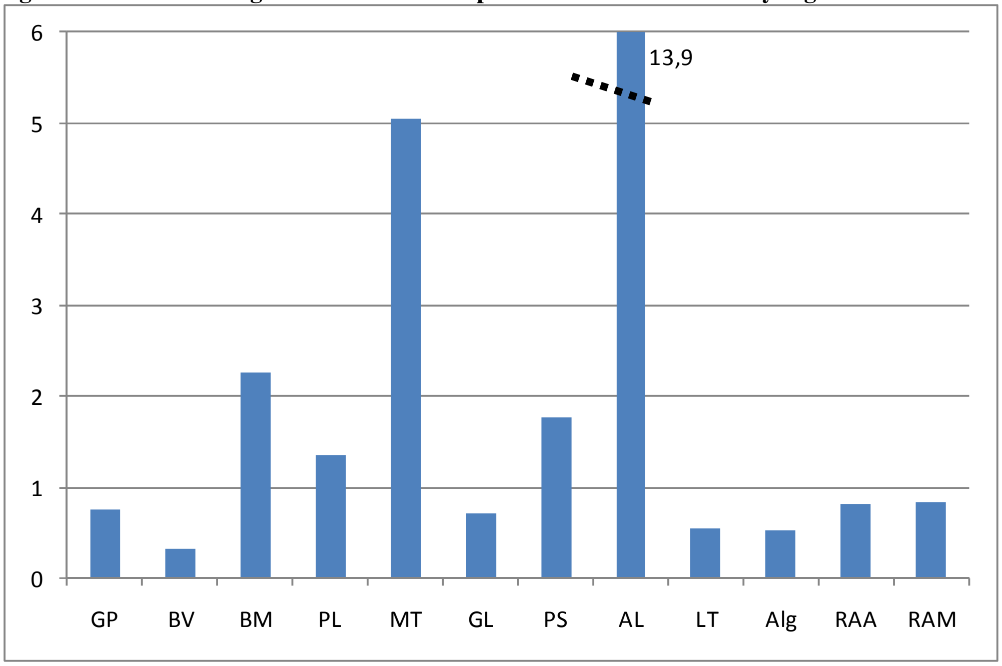
Figure 17 - Relative Emissions, Population and GVA (%) in selected regions (2005)



Source: Own elaboration using data available in http://ec.europa.eu/environment/ets and INE (2006) www.ine.pt
Note: See Appendix for full region names

In Figure 18 we provide an analysis of emissions relative to industrial GVA (including energy and construction) considering average values for 2005-2007. Here we might expect to find a stronger correlation. However, there are significant disparities between regions, even in this case. A simple regression analysis (not shown) between per capita emissions and industrial GVA has very low explanatory power (R^2=0,06 if we exclude Alentejo Litoral, a clear outlier in the data set). If we recall that the levels of emissions and allocated allowances vary between sectors, and that the largest emitter in the EU ETS is thermoelectric generation, we see that there is a significant correspondence between the regions with the highest level of emissions and the location of thermoelectric plants: this is especially clear for Alentejo Litoral (AL) and Médio Tejo (MT), since the only two Portuguese thermoelectric installations still based on coal are sited there (Sines and Pêgo, respectively). The high level of emissions in these two regions is therefore related with this type of industry and not with general economic activity, or even industrial activity. Unfortunately, we do not have data on GVA for ETS vs. non-ETS sectors in order to provide a finer analysis.

Figure 18 - Relative weight of Emissions compared to Industrial GVA by regions in 2005-2007



Source: Own elaboration using CO2 data available in http://ec.europa.eu/environment/ets and GVA from INE (2006)

Although regional GVA data includes all economic activity that is physically in each area, it should be noted that not all impacts of financial flows due to EU ETS participation occur necessarily within the same region. In particular, some installations belong to national and multinational companies, whose shareholders can be spread among different regions. Using the tax identification numbers given in the SABI database for each installation, we have selected those companies that are present in more than one region and subtracted their emissions from regional totals. For 2005, there are two regions (Alentejo Litoral and Algarve) where "true" regional emissions are below 10% of verified emissions and three regions (Baixo Mondego, Grande Lisboa and Peninsula de Setúbal) where they are below 50%. The largest companies, which account for most of the subtracted emissions, are Grupo EDP (Power sector), Cimpor (Cement) and Petrogal (Refineries) which jointly represent as much as 62% of Portuguese GHG in 2005.

In spite of this qualification, we believe it is instructive to analyse the regional dispersion of EU ETS potential economic impacts. In order to evaluate this, we calculated the net difference between the emission allowances attributed to each region (on the basis of installation location) and the actual emissions for Phase I. A positive value indicates that the sum of installations located in the region received more allowances than they used. The eventual proceeds from selling the surplus may then contribute to increase the regional GVA. Likewise, a negative difference indicates that the installations located in this region had to buy allowances and therefore transferred part of their GVA to other regions. Table 14 summarizes these effects. The last two columns show the allowance deficits (-) and surpluses (+) by region in tons and as a participation over the total Portuguese balance, respectively. The other columns illustrate the regional deficit or surplus by sector.

As mentioned in section 4, if we consider the whole of Phase I, all sectors had an allowance surplus. Yet if we do the same analysis by regions, we see that some regions had a deficit and others a surplus, as shown in Figure 19. Particularly, Alentejo Litoral, Minho-Lima and Região Aut. Madeira had deficits of around 2% of the national surplus. Still, most regions have a surplus; the ones with larger surpluses are shown in green, and these are concentrated in the coastal regions between Lisboa and Porto, where most Portuguese wealth is generated. Remarkably, the metropolitan areas (GL and GP), as well as the next most heavily populated area (PS), had very large surpluses (18,7%, 25,2% and 38,4%, respectively). These are already the richest regions in the country.

As in section 4, to determine the economic impacts of the EU ETS on regions we will consider prices of 21,73€, 15,14€ and 1,3€ per ton of CO_2 in 2005, 2006 and 2007, respectively.

Table 15 illustrates the regional significance of allowance costs or potential revenues. In the 4 regions that usually present costs (Minho-Lima (M-L), Médio Tejo (MT), Alentejo Litoral (AL) and Região Autónoma da Madeira (RAM)) these are not always very significant. The worst cases are Alentejo Litoral (AL) and Médio Tejo (MT) where the costs of the EU ETS reached for the Phase I 13,78 million and 8,62 million euros respectively. The remaining regions present surpluses, the highest corresponding to the regions of Grande Porto (GP) and Grande Lisboa (GL), with average potential revenues of approximately 26,8, and 20,8 million euros respectively.

However there is a large variation in the values as they are strongly correlated with carbon prices which fluctuated substantially along the period. Therefore the 2005-2006 values are perhaps more meaningful for our analysis. By taking the regional industrial GVA we can measure the economic relevance of the EU ETS. Thus the weight of the net allowance value on the industrial GVA for Alentejo Litoral (AL) and Médio Tejo (MT) was in range (-1,28%, -0,24%). Whereas, if we have a look to the top winner we found that is now Península de Setúbal, with a potential +0,93% weight of the net allowance value on the industrial GVA in 2006. So, eventually the EU ETS might have a significant impact for some regions if the carbon price is high enough. And that may be the case in the near future according to more stringent environmental objectives in the EU.

Since most of the emission reduction effort in Portugal is concentrated on the thermoelectric sector, there is, in territorial terms, a distortion on the energy-producing regions, which assume a disproportionate responsibility for emission control. On the other hand, the regions that do not produce energy may still contribute through energy consumption effects. Price pass-through, if allowed, could be a significant distributional factor, but so far that has not been the case because of public restrictions on consumer electricity prices, as discussed in Section 6.

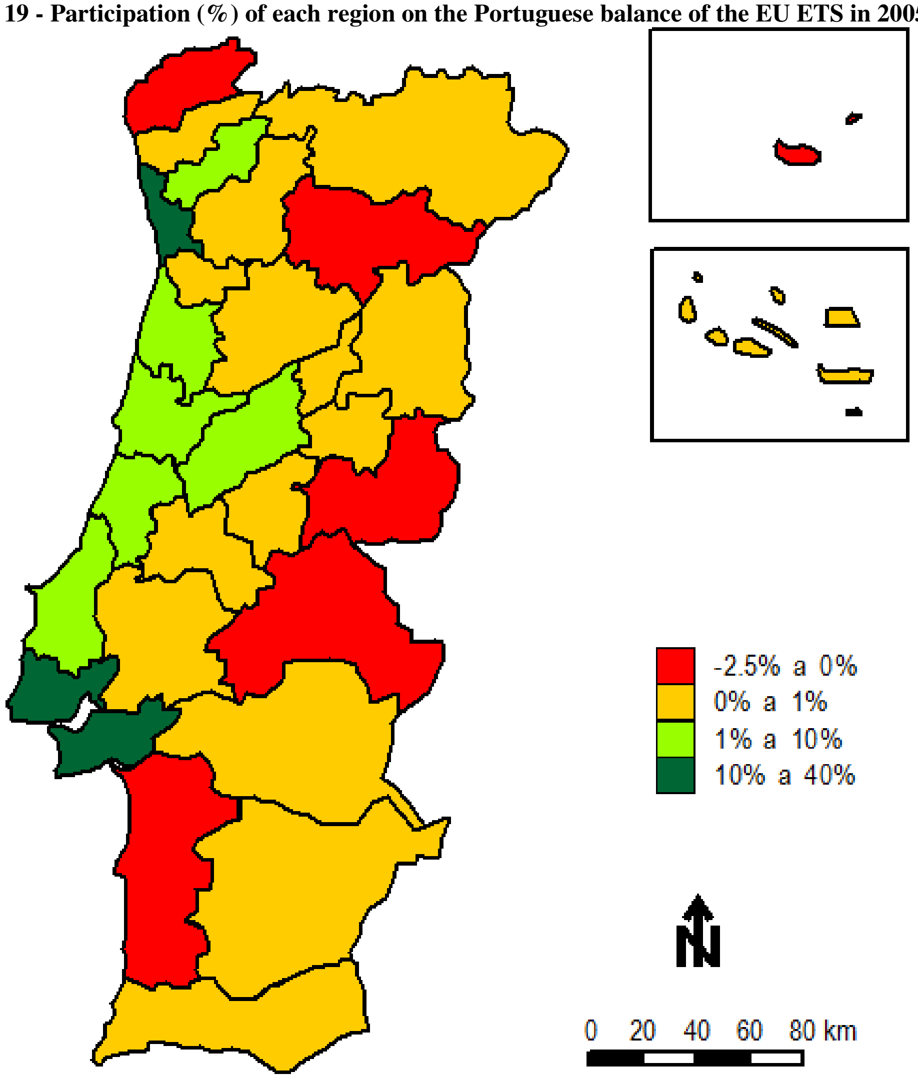
Figure 20 shows the different values for consumption and production of electricity at the regional level. Both the total production of electricity and the thermoelectric generation alone are shown. Five regions (PS, MT, Oe, GP and AL) represent 87% of Thermoelectric generation, 75% of electricity generation, and 29% of electricity consumption. Together they account for 80% of the CO_2 regulated by the EU ETS and 41% of Portuguese population. The most unequal cases are Alentejo Litoral (AL), with 27% of the national thermal electricity generation and only 2,4% of electricity consumption, and Oeste (Oe), with 16% of thermal electricity generation and only 3% of consumption. On the other hand, we have the opposite situation in Grande Lisboa (GL), which has 18% of electricity consumption and only 0,9% of thermal production.

Table 14 - Deficit (-) or surplus (+) of emission rights in 2005-2007 (t CO_2)

		Thermo-electric generation	Ceramic	Cement and Lime	Cogeneration	Other Combustion facilities	Iron and Steel	Pulp and paper	Refineries	Glass	Total	Total%
North	**Minho-Lima**		23.162		-189.382			4.853			**-161.367**	**-1,60%**
	Cávado		21.519			4.083		9.244			**34.846**	**0,30%**
	Ave				142.657	128.782					**271.439**	**2,70%**
	Grande Porto	2.206.190	19.170		76.350	19.460	66.058	-634	165.439	-23.940	**2.528.093**	**25,20%**
	Tâmega										**0**	**0,00%**
	Entre Douro e Vouga		12.768		5.182	19.520		12.101			**49.571**	**0,50%**
	Douro					-445					**-445**	**0,00%**
	Alto-Trás-os-Montes		14.431								**14.431**	**0,10%**
Central	**Baixo Vouga**		264.980		331.454	55.909		-9.634			**642.709**	**6,40%**
	Baixo Mondego		66.089	-15.291	240.599			80.097		-4.780	**366.714**	**3,70%**
	Pinhal Litoral		90.019	219.736	73.268			-582		83.639	**466.080**	**4,70%**
	Pinhal Interior Norte		94.222		26.803						**121.025**	**1,20%**
	Dão-Lafões	-235	3.843		30.353	15.168		-2.149			**46.980**	**0,50%**
	Pinhal Interior Sul										**0**	**0,00%**
	Serra da Estrela										**0**	**0,00%**
	Beira Interior Norte										**0**	**0,00%**
	Beira interior Sul							-10.724			**-10.724**	**-0,10%**
	Cova da Beira		11.950								**11.950**	**0,10%**
	Oeste		122.192								**122.192**	**1,20%**
	Médio Tejo	-4.581	33.971		16.176			37.641			**83.207**	**0,80%**
Lisbon	**Grande Lisboa**	1.965.217		-156.009	-5.933	71.125		6.509		-3.757	**1.877.152**	**18,70%**
	Península de Setúbal	2.905.071	24.058	417.222	269.240	52.722	168.016	13.477			**3.849.806**	**38,40%**
	Alentejo Litoral	-994.490			126.057				666.409		**-202.024**	**-2,00%**
	Alto Alentejo				-9.797						**-9.797**	**-0,10%**
	Alentejo Central										**0**	**0,00%**
	Baixo Alentejo		7.982		-2.397						**5.585**	**0,10%**
	Lezíria do Tejo		35.386	-26.083	5.944	-9.411		6.596			**12.432**	**0,10%**
	Algarve	-4.306	52.225	13.629							**61.548**	**0,60%**
	Região Aut. Açores	33.619			-12.698	10.091					**31.012**	**0,30%**
	Região Aut. Madeira	-196.939									**-196.939**	**-2,00%**
	Total	**5.909.546**	**897.967**	**453.204**	**1.123.876**	**367.004**	**234.074**	**146.795**	**831.848**	**51.162**	**10.015.476**	**100,00%**

Source: Own elaboration.

Figure 19 - Participation (%) of each region on the Portuguese balance of the EU ETS in 2005-2007



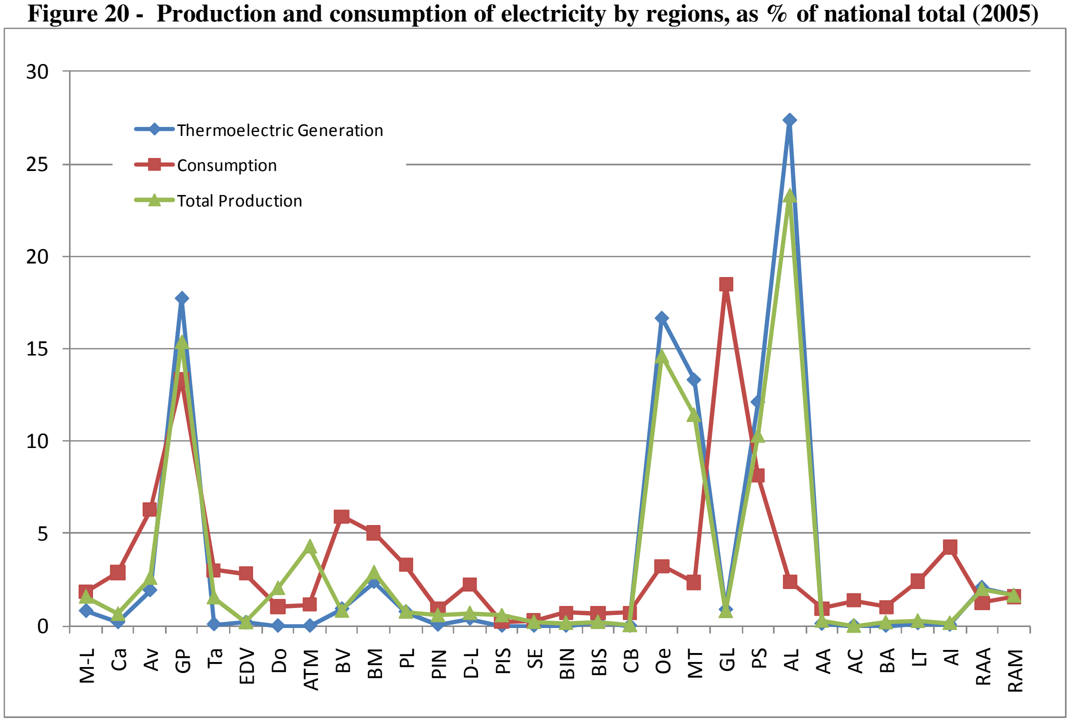
Source: own elaboration from Table 14.

Table 15 - The potential regional impacts of the EU ETS (values in 1000€ and % of Industry GVA)

		2005 Net Allowance value		2006 Net Allowance value		2007 Net Allowance value		2005-2007 Net allowance value	
	Region	**1000 €**	**% Ind GVA**	**1000 €**	**% Ind GVA**	**1000 €**	**% Ind GVA**	**1000 €**	**% Ind GVA**
North	Minho-Lima	-1.116	-0,17%	-1.172	-0,18%	-49	-0,01%	-2.337	-0,12%
	Grande Porto	6.757	0,16%	18.743	0,43%	1.360	0,03%	26.860	0,21%
Central	Baixo Vouga	4.586	0,25%	4.102	0,22%	268	0,01%	8.956	0,15%
	Baixo Mondego	3.189	0,31%	2.141	0,21%	100	0,01%	5.430	0,17%
	Pinhal Litoral	4.596	0,34%	6.217	0,44%	126	0,01%	10.940	0,26%
	Pinhal Interior Norte	1.023	0,29%	1.046	0,28%	44	0,01%	2.113	0,19%
	Beira Interior Sul	-242	-0,14%	17	0,01%	-1	0,00%	-226	-0,04%
	Médio Tejo	-7.481	-1,01%	-1.915	-0,24%	773	0,09%	-8.623	-0,36%
Lis-bon	Península de Setúbal	-404	-0,02%	20.323	0,93%	2.629	0,11%	22.549	0,35%
Alentejo	Alentejo Litoral	-10.058	-1,28%	-4.896	-0,55%	1.168	0,13%	-13.786	-0,54%
	R. A. Madeira	-1.109	-0,17%	-768	-0,11%	-124	-0,02%	-2.001	-0,10%
	Total Portugal	**-10402**	**-0,03%**	**-51374**	**-0,15%**	**-7542**	**-0,02%**	**-69317**	**-0,07%**

Source: Own elaboration and INE (2006); regions which have no installations, as well as regions where allowances costs are below |0,1%| of Industrial GVA for every year, are excluded from the Table.

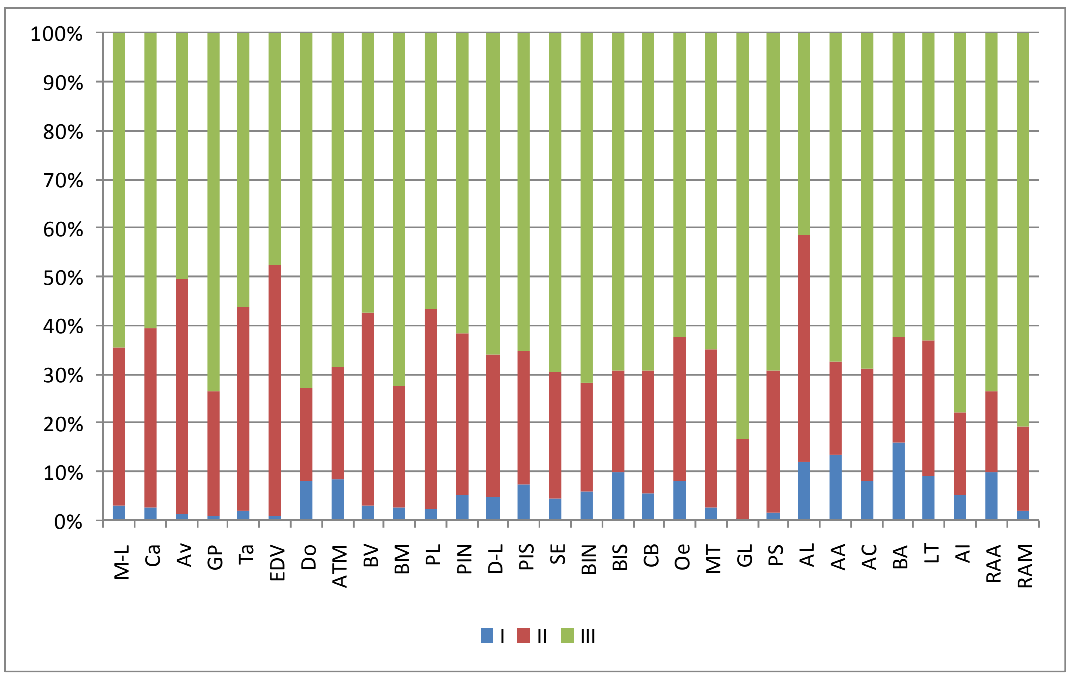
Figure 20 - Production and consumption of electricity by regions, as % of national total (2005)



Source: Own elaboration using data from http://www.dgge.pt/

Considering all sectors of economic activity, we can trace the regional economic implications of the EU ETS more closely. Figure 21 shows the sectoral composition of GVA in Portuguese regions. The division used here considers three groups of sectors: I (agriculture, hunting and forestry, fisheries and aquiculture), II (industry, including energy and construction) and III (services). There are no overall regional emissions data available to compare with EU ETS regional emissions. Nonetheless, sectors I and III are largely excluded from emission cap regulations although they account for an important part of national emissions. Sector III is paramount in Grande Lisboa (GL), Grande Porto (GP) and Península de Setúbal (PS), representing 83%, 73% and 69% of economic activity, respectively. These are also the main population centres, and may therefore be the overall main emitters of non-ETS GHG. If all sectors were covered by emission-reduction schemes, these regions could be expected to show the highest costs (instead of reaping the most potential benefits as in Figure 19).

Figure 21 - Sectoral composition of 2005 GVA in % for Portuguese regions



Source: Own elaboration using data available in INE (2006).

6.6 Portuguese Emissions Reductions in 2008 and beyond

In the second Portuguese National Plan (NAP II), covering the period 2008-2012, 152,5 million allowances (CO_2 equivalent tons) were issued, implying an annual value of 30,51 Mt (a decrease of about 17%). Between the first and second NAP there was also a modification in the industries included in the emissions market, in accordance with new EC rules and some national modifications. In Phase II part of the ceramic industry is excluded, and units of cogeneration and combustion facilities of the chemical sector are included. Comparing equivalent installations in both periods, the decrease in attributed allowances is -22,4%. Table 16 shows the sectoral distribution of these reductions.

The electricity generation sector will once more have to make the largest reduction effort. This could strengthen the conclusions that we reached for Phase I, namely in terms of the higher damage concentration in the regions where these installations are located. The actual cost will depend on hydrological conditions. Moreover, it should also be mentioned that Portuguese electricity prices are mostly regulated and cannot be freely increased.

As the costs of providing electricity have increased (due to many factors, including the EU ETS), and prices have not been raised accordingly, EDP, which is the main electricity provider in the country, was by the end of 2008 burdened with a debt (the so called tarif-deficit "défice tarifário") of around 2 thousand million euros, to be recovered from consumers, with interest, starting in 2010 (Jornal de Negócios, 2008).

The same problem with cost pass-through is noted for Spain, namely by Oberndorfer (2008), which points out that this may be one of the reasons stockmarket values of electricity firms in that country are inversely correlated with permit prices, unlike in other countries. In energy markets without price regulation, on the other hand, results indicate high levels of pass-through, leading to significant windfall profits from EU ETS participation for the power sector (Sijm et al, 2006).

Table 16 - Comparison of attributed allowances (Mt CO2) by sectors

Sector /Subsector	NAP I	NAP II (without new entrants 2005/07)	NAP II vs NAP I
Energy Supply	26,8	18,8	-29,7%
Production of electricity	21,0	13,5	-35,5%
Refineries	3,3	3,0	-6,7%
Cogeneration	2,5	2,2	-11,4%
Industry	10,1	9,8	-3,3%
Cement and Lime	7,1	7,0	-1,4%
Ceramic	1,2	1,0	-15,8%
Glass	0,7	0,7	-2,6%
Pulp and Paper	0,4	0,3	-6,9%
Iron and Steel	0,3	0,3	8,4%
Other Combustion facilities	0,5	0,5	-6,5%
Total for existing installations	36,9	28,6	-22,4%
Reserve for new entrants	1,3		
TOTAL	**38,2**		

Source: PNALE II (2008)

Table 17, like Table 12 and Table 13, presents data for emissions, coverage, and potential allowance revenues or expenses, now considering 2008 and 2009. The only sector that was "short" was, again, thermoelectric generation, while the country's ETS participation as a whole continues to show a surplus. Nonetheless, it should be noted that for these two initial Phase II years it is highly unlikely that firms have sold a significant part of their allowance surplus. There are two main reasons for this: first, Portugal had, as most other European countries, a recession in 2008-09, so firms may be holding on to allowances while expecting a rebound of economic activity; second, Phase II allowances are bankable, which means they can still be used in 2013 and beyond.

Still, if we have a look at the potential allowances sales (purchases) as % of operational revenue in 2008 (Figure 22) we will find values similar to those for 2005-06, although a lower variance of results is noticeable, especially for non-ceramic installations. We do not present the results for 2009 because of lack of financial data in the SABI database. Finally, we found again for phase II similar differences between big and small emitters as coverage values tend to be higher for small emitters than for large ones (145% against 136% for 2008 and 167% against 142% for 2009), albeit these differences are lower than for the Phase I.

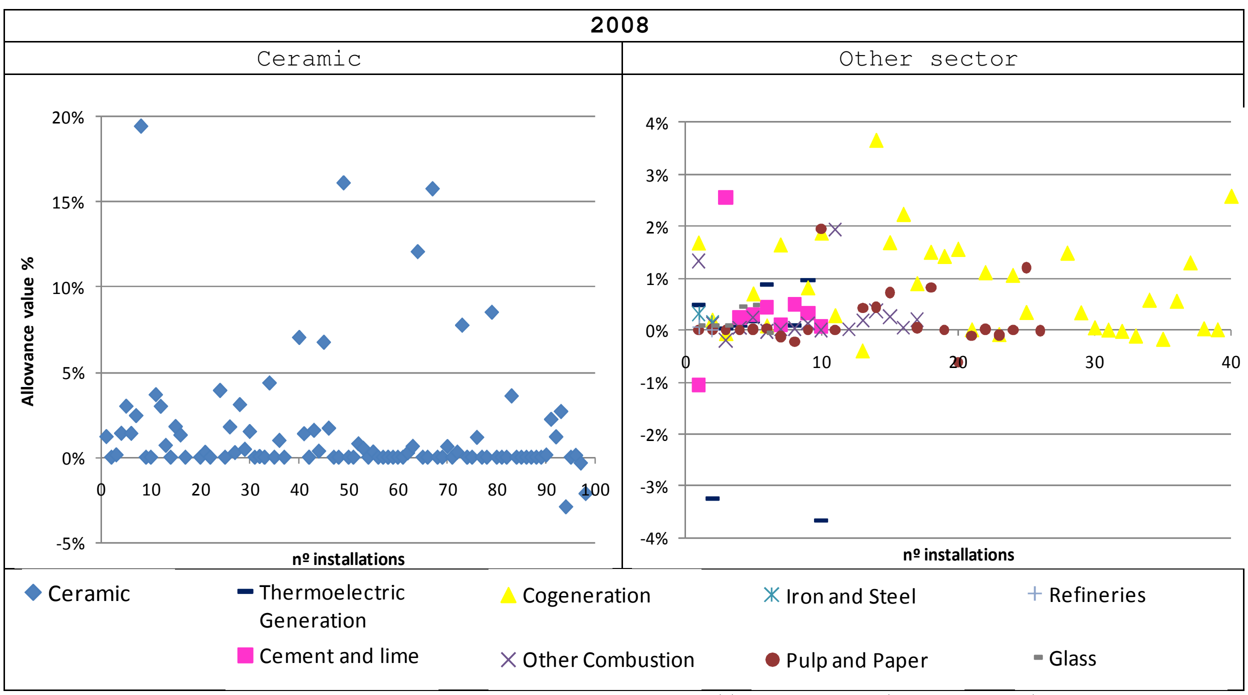
Table 17 - Emissions (in Mt), Coverage (%) and Potential financial outcome for 2008 and 2009

Sectors	Emissions 2008	Coverage %	price 18,56 €/ton
Thermoelectric generation	15,78	89	-32,93
Ceramic	0,27	211	5,54
Cement and lime	6,78	106	7,91
Cogeneration	2,53	137	17,36
Other Combustion Facilities	0,40	135	2,56
Iron and steel	0,20	164	2,43
Pulp and paper	0,34	114	0,86
Refineries	2,95	110	5,30
Glass	0,66	117	2,02
Total	**29,91**	**102**	**11,06**

Sectors	Emissions 2009	Coverage %	price 12,58 €/ton
Thermoelectric generation	15,80	89	-22,61
Ceramic	0,21	267	4,48
Cement and lime	5,45	132	22,09
Cogeneration	1,80	144	10,06
Other Combustion Facilities	0,31	174	2,88
Iron and steel	0,15	217	2,27
Pulp and paper	0,37	104	0,18
Refineries	2,62	124	7,79
Glass	0,57	135	2,52
Total	**27,28**	**118**	**29,65**

Source: Own elaboration using data available in http://ec.europa.eu/environment/ets.

Figure 22 - Potential Allowance Sales (Purchases) as % of Operational Revenue in 2008



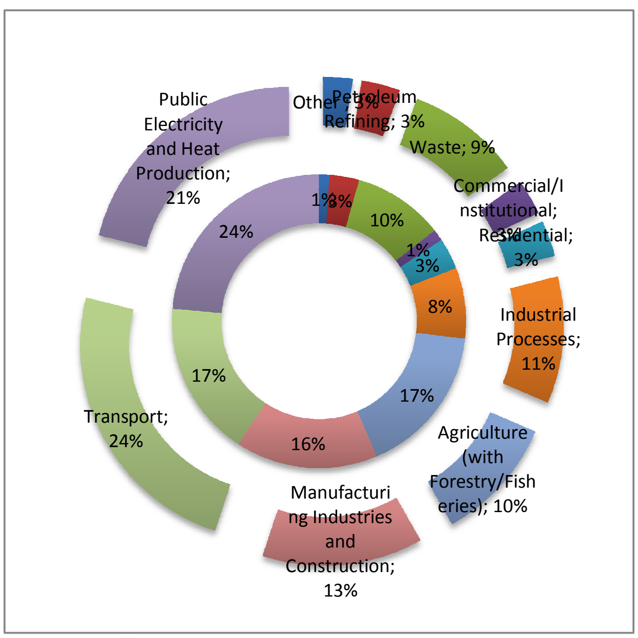
Source: Own elaboration using data available in http://ec.europa.eu/environment/ets and SABI data.
Note: All installations with zero emissions were removed from the sample for this figure, as well as a few outliers (4 with strongly positive permit revenues in 2005 and 1 in 2006).

The analysis performed above shows that Portuguese ETS targets have been, and continue to be, fairly loose. However, the EU climate and energy policy encompasses all sectors, including those outside the ETS.

Figure 23 shows the weight of each sector in national emissions. The largest non-ETS sector is Transport, which accounted for 17% of emissions in 1990 and has since grown to 24%, although other non-ETS sectors are also significant.

A few European Directives were aimed at improving the performance of uncovered sectors, namely the European Energy Performance in Buildings Directive (EPBD), the Ecodesign Directive, the Biofuels Directive and the Energy Services Directive. Such measures have uncertain effects, however, and their costs cannot easily be calculated. Moreover, the inclusion of additional regulations such as these reduces flexibility and may increase compliance costs, especially when there is no clear distinction between ETS and non-ETS policies. Two different issues can arise: the inefficiency of unlinked policies for ETS and non-ETS reductions (since marginal abatement costs will not be equal in all sectors) and the inefficiency of multiple policies within each group of sectors.

Figure 23 - Sectoral CO2 emissions (%) in 1990 (inner) and 2007 (outer)



Source: Own elaboration using data available in EEA, http://dataservice.eea.europa.eu/PivotApp/pivot.aspx?pivotid=475

It is true that a single system of emissions trading may be unsuitable for most of the uncovered sectors, because the transaction costs of registering and monitoring small emitters could be prohibitive. Theoretically, emission taxes would be capable of achieving targets in a cost-effective manner, by making sure marginal abatement costs are equal for all emitters if all sectors were covered. They would, nonetheless, impose much higher costs on emitters than grandfathered allowances, which were chosen as a starting point in EU-overall emission reduction efforts.

The same reasoning may be applicable to the full auction of allowances, which may erode the international competitiveness of domestic industries. As noted in MacKenzie et al. (2008), grandfathering allocations resembles the usual distribution of property rights embedded in command and control environmental policies thus providing a "*closer fit to existing regulatory approaches*". Nevertheless, grandfathering based on historical emissions can be seen as a reward to those installations that made low efforts to abate emissions in the past. For further insights about alternative allocation schemes see MacKenzie et al. (2008) and Böhringer and Lange (2005). They analyse the impact and optimality of implementing a dynamic relative performance mechanism for the initial allocation of pollution permits. Accordingly, the revision of the EU ETS, which will enter into force in January 2013, will reinforce the efficiency problems raised in this paragraph as it contemplates a greater share (above 50 %) of auctioned allowances.

As for the second source of inefficiencies, although climate and energy policies often claim several goals, such as energy security, technological innovation, job creation, or local environmental improvements, the GHG emissions goal is the only one that is clearly defined and well reasoned. As Böhringer et al (2009a) note, excess costs created by additional policies may be treated as the "price tag" for other goals, but these need to be quantifiable and subjected to cost-benefit analysis. These excess costs may be very significant. For instance, Böhringer et al (2009b), indicate that the overall inefficiency could translate into costs that are 100-125% too high by 2020 when compared to costs of reaching the simple emission reductions target.

As a consequence, there is a growing literature on the costs of overlapping policies. The interaction between multiple policies has been surveyed in del Rio (2007) and most recently in Fischer and Preonas (2010). Eichner and Pethig (2010) and Böhringer et al (2008) analyse the interaction between the ETS and energy taxes, while Böhringer and Rosendahl (2010) discuss the simultaneous application of emissions quotas with renewable quotas, and Tol (2009) provides a cost analysis for different schemes of non-ETS reduction. Interestingly, the latter paper finds that Portugal may be one of the few countries where non-ETS allocations may be larger than projected emissions for 2020.

Del Rio (2007) emphasizes that interactions between multiple policies are likely to be context-specific. For Portugal, a recent paper by Simões et al (2008) provides energy and environmental policy scenarios to gauge the impact of different policies on CO_2 marginal abatement costs. Theirs is a partial-equilibrium model of Portuguese energy system which compares abatement costs for different hypothetical values of emission caps, to be achieved in the period 2020-2030. The reference scenario is one where existing policies (such as the ban on nuclear power and the renewable energy goals) continue to be implemented. This scenario is compared to alternative scenarios where emissions reductions are achieved without some of the existing restrictions, i.e. with more flexibility. The simulations indicate that the reference scenario has 42-91% higher marginal abatement costs than the scenarios where existing policy restrictions are dropped. It also implies that the full costs of the Portuguese energy system from 2000 to 2030 are 10-13% higher under the current policies than they could be if all reductions were allocated efficiently).

Unfortunately, none of the Simões et al scenarios considers the possibility of emissions trading. Considering the global nature of GHG emissions and the transnational character of the EU ETS, country-specific caps are only the starting point since high-cost users can purchase allowances abroad instead of abating emissions domestically, thus lowering national compliance expenses. Thus, the authors' estimated costs, assuming that specific emission targets have to be achieved within the national energy system, are higher than necessary.

In Portugal, the current recessionary period provides a difficult background for a discussion of costly new policies, whether or not there are theoretical advantages. Nonetheless, existing fuel taxes could be further adjusted to reflect emissions in transport, and electricity prices should be allowed to gradually increase to reflect true power-generating costs. Some existing energy policies, such as a reduced VAT rate for energy or diesel fuel tax reductions, can be classified as environmentally harmful subsidies.[59] These should ideally be removed. Furthermore the European Commission energy strategy "Energy 2020" points that "*the quality of National Energy Efficiency Action Plans, developed by member states since 2008, is disappointing, leaving vast potential untapped*" despite the fact that they are generally recognised as the most economic way of meeting the EU's energy and climate change goals. For instance, houses and buildings produce on average around ¼ of national GHG in the EU.

Ad-hoc partial targets (such as those for renewable power generation, energy efficiency and so on), existing or future, should be evaluated taking into account EU ETS carbon prices, allowing their cost-effectiveness to be clearly assessed. This type of economic analysis was not performed to evaluate the National Program for Climate Change (PNAC)[60] nor is it performed in the recent National Action Plan for Renewable Energy (PNAER)[61], which lists a large number of policies, many of which are precisely ad-hoc targets. PNAER contains the mandatory estimates for quantitative policy impacts, but no cost assessment.

Finally, our own results also indicate an additional problem that may come about, due to strict renewable energy targets, namely because hydroelectricity (as well as, to a lesser extent, wind power) can show significant variability, so that reliance on such energy sources may bring large, and possibly undesirable, fluctuations in compliance costs. This kind of problems could be removed, for instance, with further infrastructure investments in order to increase electricity grid connections through the EU. Besides that, infrastructure investments could contribute to solve some concerns raised by the European Commission energy strategy "Energy 2020", as it explains that "*the market is still largely fragmented into national markets with numerous barriers to open and fair competition*".

[59] Valsecchi et al (2009) define an environmentally harmful subsidy as: "A result of a government action that confers an advantage on consumers or producers, in order to supplement their income or lower their costs, but in doing so, discriminates against sound environmental practices."
[60] http://www.apambiente.pt/politicasambiente/AlteracoesClimaticas/PNAC/Paginas/default.aspx
[61] PNAER, preliminary version for public consultation, available in http://www.dgge.pt/, June 2010

6.7 Conclusions

This work provides an analysis of the consequences of the EU ETS for Portugal at the sectoral and regional level, the last one representing a novelty in the literature. We used data on allocated and verified emissions for all regulated installations for 2005 through 2009. We provide also, and that is one the main contribution of this chapter, economic data (aggregate and firm-level), when available, to provide context and relevance by pooling together data from the Community Transaction Log data base and regional and installations financial data. The country as a whole has been long, i.e. it has received more allowances than the emissions its industries produced, for every year since the EU ETS started operating, but the distribution between sectors and regions has been uneven.

The first conclusion obtained from the raw emissions data deals with the pronounced inequality of the size distribution of Portuguese installations. Allowances are extremely concentrated in a small number of large installations. For instance, in 2005 50% of emissions came from 1,6% of installations (the four largest ones), which is similar to overall EU values (1,8% of installations account for 50% of emissions, Kettner et al, 2008). Moreover, we show that, in Portugal, small emitters have generally had better positions, even if sectoral biases are taken into account, while, at the European level, installation-size allocation disparities are analogous but less clear-cut.

A second conclusion refers to the sectoral effects of the EU ETS, where asymmetries are very pronounced. Only the thermoelectric generation sector has had significant negative balances (in 2005, 2008 and 2009), but even this sector was long in Phase I as a whole. The sectoral bias in the allotment of emissions is also clear at the European level, where the Power & Heat sector stands out for its net short positions in all periods (Kettner et al 2010). Some possible reasons for this bias are worries about competitiveness in tradable sectors and carbon leakage, as well as the apparent availability of cheaper abatement options in the sector. Interestingly, for Portugal the results for thermoelectric generation are seen to be highly dependent on weather conditions, namely precipitation, due to the necessity of replacing hydropower, which accounts for the most significant part of domestic energy production, when hydrological conditions are dry. A final point regarding the thermoelectric sector is that unlike what has happened in many EU countries, price pass-through has not been a significant feature in the strongly-regulated Iberian market.

Still, most installations in all sectors may have gained from EU ETS participation, with firms in sectors like ceramic and cogeneration showing considerable potential for additional revenues. Taking firm-level financial data into account, possible allowance sales are above 5% of operational revenues in most of the installations in these two sectors, and a few reach values above 20%. These results, however, need to be viewed with caution for various reasons. First of all, these sectors encompass many small installations, for which transaction costs can be a serious drain on resources. Secondly, low verified emissions can be a result of abatement efforts, entailing costs for firms that would need to be evaluated against possible allowance sales income. Thirdly, there is a clear difference between long and short positions: while the latter imply that firms need to buy additional allowances to make up for their deficit, the former are not necessarily brought to market. This is especially true for 2008 and 2009 data, as unsold allowances can be used in later years.

A third set of conclusions deals with the regional impact. As expected, there is a high concentration of regulated emissions in a limited number of regions. Although the EU ETS does not have a specific regional focus, it is still instructive to look at the distributive consequences of participation. We find no obvious relationship between regional emissions and economic data (namely Industry GVA). Regions that house the main thermoelectric installations (in particular, those that have coal-based power production) show the highest asymmetries between emissions and Industry GVA and account for the greatest losses (allowance costs above 1% of Industry GVA for at least one year). We also find evidence for larger EU ETS surpluses in the richer Portuguese regions, where non-ETS sectors account for more of the produced wealth.

Finally, it should be emphasized that the transport sector, agriculture, households and other services are responsible for a large share of emissions but remain unregulated by the EU ETS. We provide a discussion of the literature on overlapping policies, highlighting two different issues: the inefficiency of unlinked policies for ETS and non-ETS reductions (since marginal abatement costs will not be equal in all sectors) and the inefficiency of multiple policies within each group of sectors. And this fact probably reinforces our concerns with the regional distribution of environmental costs. As policy interactions can be very complex, an important recommendation is for context-specific analysis, which indicates a need for more applied research for individual countries.

Future research should focus on a regional-sectoral model of interaction, considering the key sectors, including EU ETS covered and uncovered sectors, or on the use of a GEM for the Portuguese economy that simulates alternative policies. Another important line of work is to provide econometric testing of the relationship between firm-level economic data and emissions (as is done for Germany in Anger and Oberndorfer, 2008; even though they worked with a small sample of firms, only 419).

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APPENDIX

Table 18 - Regional CO_2 regulated Emissions, GVA and Industrial GVA (2005)

	Portuguese Regions Nuts III		CO_2 (ton)	CO_2 (%)	GVA %	Industrial GVA %
North	Minho-Lima	M-L	182.013	0,5	1,5	1,9
	Cavado	Ca	28.426	0,1	3	4,2
	Ave	Av	253.848	0,7	3,7	6,7
	Grande Porto	GP	3.239.134	9,3	12	12,4
	Tâmega	Ta	0	0	2,9	4,5
	Entre Douro e Vouga	EDV	74.387	0,2	2,2	4,4
	Douro	Do	3.998	0	1,4	0,9
	Alto-Trás-os-Montes	ATM	10.936	0	1,4	1,2
Central	Baixo Vouga	BV	590.515	1,7	3,5	5,5
	Baixo Mondego	BM	2.257.925	6,5	3,3	3,0
	Pinhal Litoral	PL	1.792.759	5,2	2,5	4,0
	Pinhal Interior Norte	PIN	142.624	0,4	0,8	1,0
	Dão-Lafões	D-L	76.735	0,2	1,9	2,3
	Pinhal Interior Sul	PIS	0	0	0,3	0,3
	Serra da Estrela	SE	0	0	0,3	0,2
	Beira Interior Norte	BIN	0	0	0,7	0,6
	Beira interior Sul	BIS	31.220	0,1	0,6	0,5
	Cova da Beira	CB	546	0	0,6	0,6
	Oeste	Oe	96.261	0,3	2,8	3,3
	Médio Tejo	MT	4.122.429	11,9	1,8	2,2
Lisbon	Grande Lisboa	GL	4.796.533	13,8	31,8	20,8
	Península de Setúbal	PS	4.011.021	11,6	5,2	5,8
Alentejo	Alentejo Litoral	AL	11.131.160	32,1	1,3	2,3
	Alto Alentejo	AA	40.307	0,1	1	0,7
	Alentejo Central	AC	0	0	1,4	1,3
	Baixo Alentejo	BA	8.191	0	1	0,9
	Lezíria do Tejo	LT	383.273	1,1	2,1	2,2
	Algarve	Al	517.755	1,5	4,1	2,9
	Região Autónoma dos Açores	RAA	463.588	1,3	2	1,4
	Região Autónoma da Madeira	RAM	458.295	1,3	2,9	1,9
	Portugal		**34.713.872**	**100**	**100**	**100**

Source: Own elaboration using data from INE (2006).

Table 19 - Percentage % of emissions covered by the SABI database

Sector	Coverage 2005	Coverage 2006	Coverage 2007
Thermoelectric generation	34,04%	32,18%	35,74%
Ceramic	85,72%	85,62%	70,93%
Cement and lime	100,00%	100,00%	100,00%
Cogeneration	100,00%	98,32%	78,37%
Other Combustion facilities	60,88%	79,55%	60,48%
Iron and Steel	100,00%	100,00%	100,00%
Pulp and paper	97,56%	97,65%	98,37%
Refineries	100,00%	100,00%	100,00%
Glass	74,23%	96,46%	70,68%
TOTAL	**59,06%**	**58,98%**	**62,60%**

Source: Own elaboration

7. Conclusions and Future Perspectives

Today economies face serious environmental problems, related in part with the emissions of greenhouse effect gases, in particular CO2. This environmental conscience jointly with the assumed commitments to change the present route, has taken various countries to apply policies that modify the harmful environmental behaviour.

Any policy, and mainly when it uses price driven instruments, affects in some way the economic activities, as well as economic aggregates as employment, prices, GDP, etc. Thus, it is important to evaluate the economic impact of these environmental policies.

A particular kind of policy known as GTR has been evaluated and implemented in many countries. It guarantees the neutrality of state revenues, recycling the environmental tax revenues in the reduction of other taxes with dead weight loss for the economy. In such a way, a double dividend, or double benefit can be reached, when improving the environment and the efficiency of the economy.

The evaluation of these policies in empirical literature, when GEM are used, has proved to be trustworthy and realistic, (comparing to evaluations with partial equilibrium models, for example). As had been done for other countries, we thought it would be relevant to make this kind of study for Portugal.

We investigated what kind of models was used for these studies, how the diverse economic activities and economic agents were modelized, and how environmental variables were introduced in an economic model.

Thus following some examples in the literature we constructed the Portuguese model. We calibrate it through a Social and Environmental Accounting Matrix which, for a benchmark year, included all relevant economic and environmental information.

After the model was calibrated and correctly functioning, we did some simulations to evaluate and present the economic effects of a GTR implemented in the Portuguese economy. Two kind of reforms where studied:

first, a reform with introduction of an environmental tax on fossil fuel consumption and recycling of revenues through SSC reduction; and second, the same reform but with recycling of revenues through lump sum transfers. We also made a sensibility analysis using three different values for the environmental tax.

We conclude that, with a GTR with reduction in the social contributions due by employers, there is not a "double dividend" following the definitions presented in chapter one. We only can say that this policy lead to an "employment double dividend", since it has important environmental effects and simultaneously improve employment. However, this reform would have a cost in economic terms, decreasing the real value added generated by the economy by a 0,4%, leading to a redistribution of the economic activity between the different sectors with positive but moderate effects on the price index (+1,3%) and no significant welfare effects. With a GTR with lump sum transfers there is a "double dividend" following the "weak" definition of Goulder, the definition of the public finance approach, and the definition of the environmental approach (see chapter one). Through Gimenez and Rodriguez definition we only obtain the first dividend but not the second one. In this reform we obtain environmental and welfare gains, but have an economic cost of -1%, measured in real GDPpa, with positive but moderate effects on the price index (+1,4%).

The environmental improvement is slightly bigger in the simulation with lump sum transfers, because this is more focused in the environmental goal. The electricity sector is the one that reduces more emissions in both reforms.

The sectors most damaged in production and prices are, as expected, the more energy intensive sectors. In terms of trade balance, we have a reduction of the energy bill in both kinds of simulation.

When we raise the environmental goal, the economic cost rises in a bigger proportion, indicating a convex relationship, but this is not the case for the welfare costs. As we reduce emissions, there are economic costs that negatively affect welfare, but the environmental components become stronger and make these costs decrease.

It is important to notice that these simulations present very modest results concerning job creation, GDP variation and prices, because full employment is assumed as a benchmark and, in reality, Portugal has a rate of unemployment clearly different from zero. On the other hand, the model does not consider the possibility of adaptation to the carbon tax through technology change and through measures to improve efficiency. Therefore, the scenario is more pessimistic in terms of tax induced employment variation. Beyond this, we consider a unilateral application of the tax by Portugal.

In parallel with the work above, we did a sectoral and regional study of another environmental policy (which is already in place), the ECM. Due to its complexity and for lack of data, we could not use the constructed GEM to do such evaluation. We used data on allocated and verified emissions for all regulated installations from 2005 through 2009. We provide also economic data (aggregate and firm-level), when available, to provide context and relevance, by pooling together data from the Community Transaction Log data base, regional data and individual installations financial data. The country as a whole has been long, i.e., it has received more allowances than the emissions produced by the regulated industries, for every year since the EU ETS started operating; however, the distribution between sectors and regions has been uneven.

From this analysis of the EU ETS we conclude that there is a pronounced inequality of the size distribution of Portuguese installations. Allowances are extremely concentrated in a small number of large installations. Moreover, we show that, in Portugal, small emitters have generally had better positions, even if sectoral biases are taken into account, while at the European level installation-size allocation disparities are analogous but less clear-cut.

At a sectoral level, the asymmetries are very pronounced. Only the thermoelectric generation sector has had significant negative balances (in 2005, 2008 and 2009), but even this sector was long for the whole period.

Still, most installations in all sectors may have gained from EU ETS participation, with firms in sectors like ceramic and cogeneration showing considerable potential for raising revenues from permit sales.

At the regional level, there is a high concentration of regulated emissions in a limited number of regions. We find no obvious relationship between regional emissions and economic data (namely Industry GVA). Regions that house the main thermoelectric installations (in particular, those that have coal-based power production) show the highest asymmetries between emissions and Industry GVA and account for the greatest losses (allowance costs above 1% of Industry GVA for at least one year). We also find evidence for larger EU ETS surpluses in the richer Portuguese regions, where non-ETS sectors account for much of the produced wealth.

It should be emphasized that the transport sector, agriculture, households and other services are responsible for a large share of emissions but remain unregulated by the EU ETS. We provide a discussion of the literature on overlapping policies, highlighting two different issues: the inefficiency of unlinked policies for ETS and non-ETS reductions (since marginal abatement costs will not be equal in all sectors) and the inefficiency of multiple policies within each group of sectors. And this fact probably reinforces our concerns with the regional distribution of environmental costs. As policy interactions can be very complex, an important recommendation is for context-specific analysis, which indicates a need for more applied research for individual countries.

From the studies made in this thesis, we can make some policy reflections. First, we can say that it could be viable from an economic and political point of view to implement a GTR with perhaps a kind of total or partial exemption to the transport sector, which is already burdened with a high level of taxation, basing the main incidence of fossil fuel taxes in the consumption for electricity production, services or households. Second, a hybrid policy that concerns EU ETS plus an environmental tax for the non covered sectors, in a GTR context, would be a good bet, as in this way we make all CO2 emitters responsible and minimize the cost of the reform. The auctioning of licenses instead of grandfathering would function as a CO2 tax for the covered sectors, which would be coherent with some of the reflections raised by the European Commission for the Post Kyoto design of the EU ETS.

Future research should focus on a model of interaction of diverse environmental policies, like EU ETS and GTR, or on the use of a General

Equilibrium Model for the Portuguese economy that simulates alternative policies, but accounting for the actual unemployment level in the Portuguese labour market. Another important line of work is to provide econometric testing of the relationship between firm-level economic data and emissions. It would also be interesting to develop an integrated model to link the Portuguese GEM with partial equilibrium models, like technological or microeconomic models.