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Environmental Tax on Products and Services Based on Their Carbon Footprint: A Case Study of the Pulp and Paper Sector

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Abstract

The main aim of this work is to define an environmental tax on products and services based on their carbon footprint. We examine the relevance of conventional life cycle analysis (LCA) and environmentally extended input-output analysis (EIO) as methodological tools to identify emission intensities of products and services on which the tax is based. The short-term price effects of the tax and the policy implications of considering non-GHG are also analyzed. The results from the specific case study on pulp production show that the environmental tax rate based on the LCA approach (1,8%) is higher than both EIO approaches (0,8% for product and 1,4% for industry approach), but they are comparable. Even though LCA is more product specific and provides detailed analysis, EIO would be the more relevant approach to apply economy wide environmental tax. When the environmental tax considers non-GHG emissions instead of only CO_2, sectors

such as agriculture, mining of coal and extraction of peat, and food exhibit higher environmental tax and price effects. Therefore, it is worthwhile for policy makers to pay attention on the implication of considering only CO_2 tax or GHG emissions tax in order for such a policy measure to be effective and meaningful.

Keywords: Environmental tax; Life cycle analysis; Environmental input-output analysis

1. Introduction

There is an increasing concern about climate change around the globe, as various studies reveal the definitive effect of global warming and the urgent need for a global response to a reduction in greenhouse gases[i] (GHG) (IPCC, 2007). Unsustainable consumption and production patterns coupled with population growth (7 billion according to the recent UN demographics (UN, 2011)) and socio-economic development are among the major driving forces behind the increase of anthropogenic GHG emissions. These concerns about the increasing climate change effect have led policy makers to search for approaches to limit GHG emissions due to consumption and production. The issue of changing production and consumption patterns has been brought into policy agenda as one of the climate change mitigation options since the Earth Summit in Rio de Janeiro (UN, 1992). It was also a central agenda in the World Summit for Sustainable Development (WSSD) in Johannesburg (UN, 2002). More recently the Stern Review of the Economics of Climate Change strongly argued for the need for aggressive and immediate actions to mitigate the potential costs of climate change due to consumption and production (Stern, 2006).

Strong environmental policy that limits the growing dependence on fossil fuel is indispensable in order to reduce the increasing trend of GHG emissions. This can be achieved through a regulatory based approach, the so called command-and-control, as well as through market based instruments. The command-and-control approach focuses on achieving reduction of emissions by directly regulating the activities of firms and individuals by setting standards on the energy efficiency of manufacturing processes, on fuel content and use, and so on. Though it has been used in GHG emissions management, this approach is often criticized for its high administrative cost of implementation. Market based instruments, which are based on the principle of economic market mechanism are alternatives to the command-and-control approach. Tradable permit and environmental tax are among the main tools that are used in GHG reduction strategies. Such economic tools provide incentives to polluting industries for any positive measure they take to reduce their emissions through market signals. A properly designed market instrument can play an important role in moving the world closer to sustainability by reducing human related emissions due to production and consumption. The cost effectiveness and the dynamic incentives for technology innovation are the two most notable advantages over the command-and-control (Jaffe and Stavins, 1995). In this study, methodological issues related to the definition and estimation of environmental tax will be discussed.

The principle behind an environmental tax is that a defined levy is introduced on environmentally polluting products[ii] based on the potential cost of climate change effects caused by the production and consumption of these products. By internalizing the negative externalities (e.g. GHG emissions) and reflecting them in the price, the introduction of an environmental tax would raise the prices of polluting goods and services and decrease the relative prices of environmentally friendly products. This would give consumers more information on the environmental profile of the products and services they purchase and could lead to a more sustainable consumption and production through promoting environmentally friendly products. However, distributional effects and global competitiveness are among the main shortcomings of environmental tax and the manner in which environmental tax treats different income groups in an economy is an important element that limits its applicability. Environmental tax is often considered as a regressive tax as it imposes a higher burden on low-income households than high-income households. In addition, imposing an environmental tax increases the cost of highly polluting energy sources and consequently increases the cost of production. Hence, domestic industries may lose their global competitiveness when they are competing with foreign producers from countries where similar environmental policies are not applied. Therefore, policy reforms are required in order to counter balance such negative implications and to make these instruments worthwhile (Fullerton et. al., 2008; Parry et al., 2003; Pterba, 1993).

One of the challenges with environmental tax implementation is the identification of a proper tax rate as setting the desired level of tax that could influence both consumers and producers is a very complex issue. There are different ways of evaluating the price for GHG emissions. Some use the cost-benefit analysis, so that the environmental tax is set to be equal to the social cost of GHG emissions as a marginal social cost of emitting one extra ton of CO_2 or CO_2 eq. However, such estimations are subjected to high uncertainties in measuring how temperature responds to change in atmospheric CO_2 concentration (climate sensitivity), in determining the time lag between change in temperature and CO_2 concentration, in the choice of discount rates used in the valuation of climate change impacts occurring in the future, in equity treatment (how the same impact is valuated in different geographical regions where they exhibit differences in the willingness to pay to avoid impacts) and in the valuation of economic and non-economic impacts and treatment of possible catastrophic losses (Clarkson and Deyes, 2002; Yohe et al., 2007). Others use the marginal abatement scenario, which considers the cost of reducing an additional emission unit (den Elzen et al., 2007; Hourcade and Shukla, 2001; Rao and Riahi, 2006;). Assumptions on marginal abatement costs are also subject to a high level of uncertainties. For these reasons, we considered the CO_2 tradable permit price by EU-Emissions-Trading System (EU ETS) as an equivalent environmental tax. The EU ETS was launched in 2005 with a target of reducing GHG emissions to at least 20% below 1990 level by year 2020. It works on the principle of “cap and trade”. Industries or power plants under this scheme have a limit on the total amount of emissions they can release. They receive emissions allowances within their cap and they can sell to other industries when their emissions are below the limit or buy from others when the emissions excide the limit. This flexibility can ensure emissions reduction in a cost-effective way. The price of CO_2 or GHG emissions is determined by the market supply and demand, and it depends on the relative availability of allowances, the costs of emissions abatement efforts and economic conditions (European Commission, 2008). The EU ETS established a uniform carbon price for selected industries across the EU. The scheme covers around 11, 000 installations in 30 countries, and includes power and heat generators, oil refineries, and industries such as cement, lime, glass and ceramic materials, and pulp and paper. It allows having a uniform price of emissions across all sectors of the economy. The EU ETS carbon price of a permit could be represented as an environmental charge for each industry and be regarded as an equivalent to environmental tax. Therefore, we considered the permit price as a cost of emissions to define an environmental tax in this case study.

An important issue in the design of an environmental tax, and the central objective of this work, is how to differentiate between different products according to their particular emissions. The emissions associated with a product starts from the extraction and production of inputs necessary to produce the final product (e.g. a car). Emissions also occur during its production (e.g. emissions released during the production of a car), during its use (e.g. emissions released by burning the fuel in a car), and after its use (e.g. dismantling the car and recycling its components and/or disposing it in a landfill). The first question to address is which of these emissions should be associated with a given product in order to place an environmental tax on it. Should we consider only the emissions from its production (also called "direct emissions") or the sum of emissions over the whole life cycle of the product, from materials extraction to its final disposal? Clearly, different boundaries of emissions assessment will lead to very different results, implying different measures (e.g. different environmental taxes). Therefore, we should pay attention to the choice of methods for the estimation of a product's emissions. In this paper, we investigate the variability in an environmental tax when it is based on different methods to calculate GHG and CO_2 emissions intensities of products and/or services in the Spanish economy in general. The case of pulp and paper industry is analysed in detail. Environmental input-output (EIO) of both sectoral and product/commodity approaches, and Life Cycle Assessment (LCA) are used as methodological tools to calculate the emission intensities, which are then translated into environmental tax.

Furthermore in this work, the methodological approaches to calculate both CO_2 and GHG emissions intensities and the related tax on sectors, product groups and specific products are outlined and the choice of the most appropriate methodological approach that best determines the pollution embedded in a product or service for defining an environmental tax is discussed. Finally, conclusions are drawn and the policy implications of the results are presented.

2. Methodology

As mentioned above, the definition of environmental tax is based on the carbon footprint of products and services in the Spanish national economy. Here the most important issue to be addressed is which methodology to implement in order to have an optimal estimation, as the selection of one methodology over the other has consequences on the outcome as different approaches have different ways of defining functional unit, cut-off and allocation rules. This also affects the policy implication that can be drawn from the results. Therefore, assessing the relevance of methodologies is an important step. So far there are no internationally standardized methodological frameworks for consistent estimation of products' and services' carbon footprint. The conventional life cycle analysis (LCA), environmentally extended input-output (EIO) models and more recently hybrid-IOLCA models are the main approaches currently used (Matthews et al., 2008; Suh, 2004).

Conventional LCA is the most popular tool used to assess environmental implication of products and services (Guinée et al., 2002; ISO, 2006b) and product carbon footprinting. The greenhouse protocol of the World Resource Institute (WRI) and the World Business Council on Sustainable Development (WBCSD), the PAS 2050 of British Standards Institute, and ISO 14044, ISO 14064 are among the main proponents of LCA guidelines and standards used nowadays in carbon footprinting.

LCA is a bottom-up approach that is built upon a comprehensive study of systems at unit process level. Materials and energy used in the entire life cycle of a product, and the associated emissions released to the environment from each constituent process involved in the life cycle of the product are then pulled together to represent the emission intensity per its functional unit[iii]. Conventional LCA approach can be represented in a matrix form, which covers an infinite order of interaction of processes within selected boundaries (Heijungs, 1994). Such a matrix description of LCA also allows us to connect the conventional LCA approach with EIO models. The emissions $\breve{m}$ released by producing a given functional unit $\breve{y}$ are calculated as:

$$\breve{m} = \breve{b}'\breve{A}^{-1}\breve{y} \qquad \text{Eq - 1}$$

where $\breve{b}$ is a vector of emissions per unit process and $\breve{A}$ is the technology matrix, in which each element represents the inflow or outflow of energy or material from one process to another per functional unit.

Generally speaking, the LCA approach is the most dominant tool to estimate emission intensity at a product level. However, it is time and labour intensive to cover all products and services in an economy, as well as being subject to errors due to its constraint to cover all systems in the supply chain. Inclusion and exclusion of systems are usually made on a subjective base (ISO, 2006a). Often main on-site processes and some inputs from upstream processes are considered in the analysis, which may omit important inputs of the system and could result in truncation errors. A study by Lenzen (2000) suggested that errors due to exclusion of processes from the system and an incomplete boundary selection could be as high as 50%.

The other approach applied in this case study is EIO analysis. EIO is a top-down approach used to account for resource consumption and emission release based on economic input-output tables (Miller and Blair, 2009). The approach uses generic data at national levels to evaluate the emission intensity of all industries in an economy (vector $\boldsymbol{m}$ in the equation below) to produce the output necessary to satisfy a given final demand. The EIO model is derived from the Leontief input-output table, which was initially developed by Wassily Leontief in the 1930s, for which he received a Nobel Prize in Economics. The model is symmetric in nature as it is based on a one-to-one industry and product relationship, i.e. each industry is assumed to produce only one product and each product is produced by only one industry. It is represented in matrix notation as follows:

$$m = b^{'}(I - A)^{-1} \qquad \text{Eq} - 2$$

I is nxn identity matrix, where n stands for number of industries in the economy. ***A*** is nxn matrix of technical coefficients, whose element $\boldsymbol{a_{ij}}$ measures the flow from industry *i* required to produce 1€ output of industry *j*. ***b*** is a vector of industrial emissions in which each element b_i represents the amount of emissions released to produce 1€ output of industry *i*.

On the premise that an industry may produce more than one product, another type of IO model that expands the traditional Leontief model was developed, based on the make and use table. This kind of accounting makes it possible to explicitly consider secondary products and by-products. The IO model based on make and use table is often referred to as the commodity-by-industry input-output model. It was first introduced by Sir Richard Stone (Stone, 1961) and was proposed by the United Nations as a standard for data gathering in its 1968 System of National Accounting (UN, 1968). The commodity-by-industry input-output model is represented by two matrices, the make matrix (***V***) and the use matrix (***U***).

The ***V*** matrix ***(***also called the output matrix***)*** is a product-by-industry matrix, shows how each industry makes a product. Each column refers to product and each row to industry. The element v_{ij} of the transaction matrix ***V*** represents the amount in € of product *j* produced by industry *i*.

The use matrix ***U*** (input matrix) shows how products are consumed by industries. Columns and rows are represented by industries and products, respectively. Each element u_{ij} of the use matrix stands for the amount of purchase of product *i* by industry *j*. The total requirement matrix is then derived from these tables and matrices (the detailed formula is explained elsewhere (Miller and Blair, 2009)):

$$\tilde{m} = b^{'}(D(\tilde{I} - BD)^{-1} \quad \text{Eq - 3}$$

D is a product output proportion (also called market share or supply coefficients matrix) derived from the make matrix ***V*** and product total output vector ***q*** as:

$$D = V\hat{q}^{-1} \quad \text{Eq - 4}$$

Each element d_{ij} represents the share of total product *j* output which is produced by industry *i*. ***B*** is the commodity-by-industry direct requirement matrix, which indicates the technological requirement of each product by industries. The matrix ***B*** is derived from the use matrix ***U*** and the vector of industry total output ***x*** as:

$$B = U\hat{x}^{-1} \quad \text{Eq - 5}$$

Each element b_{ij} denotes input requirement of product *i* associated with output of industry *j*.

Both EIO models have important features that make them one of the potential methodological approaches for carbon footprinting of products and services. One of these features is their completeness. EIO models link all industries in a given economy and hence facilitate an assessment of the interdependency of industries. Another feature is their ability to assess both direct and indirect emissions explicitly. These features together encapsulate all emissions associated with the final demand of a given product. Through path analysis, they also allow a detailed tracing of the main sources and drivers behind each. Carbon footprint also aims to quantify all direct and indirect emissions through the life cycle of a product without disregarding exactly where the emissions occur and these make EIO models suitable methodologies for carbon footprinting. However, EIO models lose process specificity due to the high level of aggregation, limiting their application to study carbon footprint at individual product level.

In our study, both symmetric EIO model and commodity-by-industry EIO model were applied to analyse the carbon footprint of products at an industry and product group level, respectively. A detailed analysis on an individual product level was carried out specifically with the application of conventional LCA to the paper pulp manufacturing process.

Without regarding which methodology is used to calculate the emission intensities of products or services, the environmental tax $\boldsymbol{\tau}$ is calculated by multiplying the emissions intensity vector obtained from both LCA and EIO approaches by the cost of emissions, $\boldsymbol{\varphi}$:

$$\tau = \varphi C \qquad \text{Eq - 6}$$

where $\boldsymbol{C}$ is a vector of emission intensity (vectors $m, \tilde{m}$ and $\breve{m}$ in eq. 1, 2 or 3 respectively) and $\boldsymbol{\varphi}$ is the emissions cost expressed in €/ton CO_2 or €/ton CO_2 eq. The multiplication of the intensity vector by the emissions price will increase the price of products or services in proportion to their emission intensities assuming that the market is competitive and there are constant returns to the scale. However, such kinds of assumptions do not represent the real market system and are used only in partial or general equilibrium[iv] analysis of indirect tax effect, in which the possible increasing returns to scale are ignored (Creedy and Martin, 2000). The effects of the imposition of environmental tax on the price of products and services are explained below.

The vector of sectoral prices before the introduction of the environmental tax is defined as a function of tax-exclusive price $\boldsymbol{P_0}$ and ad valorem tax $\boldsymbol{t}$:

$$P_1 = P_0 (1+t) \qquad \text{Eq -7}$$

The new vector of sectoral price after the introduction of environmental tax will be:

$$P_2 = P_1 (1+\tau) \qquad \text{Eq - 8}$$

Combining equation 7 and 8, we find:

$$P_2 = P_0 (1+t^*) \qquad \text{Eq - 9}$$

where $\boldsymbol{t}^{*}$ is the effective tax rate, defined as a percentage increase of tax-exclusive sectoral price $\boldsymbol{P_0}$ after the addition of an indirect tax, $\boldsymbol{t}$, and an environmental tax, $\boldsymbol{\tau}$ (Creedy and Sleeman 2006):

$$t^{*} = t + \tau(1+t) \qquad \text{Eq - 10}$$

System considerations

For the LCA approach, we considered the production of paper pulp in Spain as a case study in order to compare with EIO approaches for the application of an environmental tax.

Pulp mills convert wood into fiber pulp for paper making process, a mechanism comprises highly energy intensive processes such as pulping and drying (Worrell et al., 2008), which makes it one of the most energy consuming sectors. Pulping processes are broadly classified as mechanical and chemical pulping, with chemical pulping being the dominant process in pulp and paper industries, accounting for 75% of the world's wood pulp supply (Das and Houtman, 2004). Kraft (sulphate) pulp is the most widely used chemical pulping process, and we have thus chosen this production process and the carbon footprint of sulphate pulp with total chlorine free bleaching process as a case study.

The functional unit of the system is production of 1 ton of air-dried (10% moisture content) Kraft pulp bleached at plant. The main material and energy inputs are modelled using secondary data from González-García et.al (2009) and the ecoinvent database (Hischier, 2007).

Figure 1 describes the system boundaries and main processes included in the study. These are logging operation (including log production from forest trees, transportation of wood logs from forest area to pulping mill), wood handling, chemical extraction and production, chemical pulping and bleaching processes, the drying process, chemical recovery and waste water treatment process and finally, on-site energy production. We did not take the end-of-life and disposal phases of the product into consideration in the system boundaries, as pulp products are mostly used as an intermediate process that undergoes further processing before disposal, as well as keeping consistent with the EIO approach, where only cradle-to-gate life cycle impact of products are assessed.

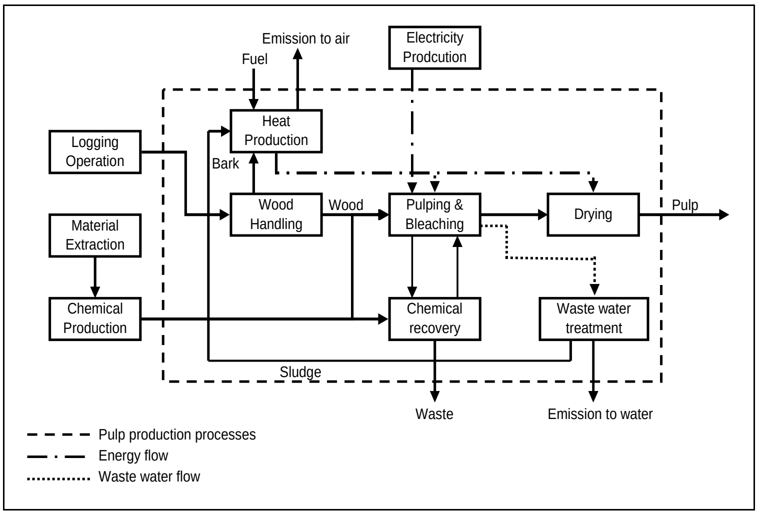


Figure 1 LCA system boundary of Kraft pulp production

For EIO approaches, the entire Spanish economy was considered as a system boundary. For the industry based EIO model, the production of pulp was represented as an economic activity in the Manufacture of Pulp, Paper and Paper

Product sector (industry 21 in the Spanish industry classification). Therefore, the emission intensity of this sector was taken into account. Whereas, the commodity-by-industry EIO approach identifies that industry 21 produces two products groups, namely *Pulp, Paper and Paperboard* (product group 29) and *Articles of Paper and Paperboard* (product group 30). Here the production of pulp was represented as an economic activity that produces product group 29, *Pulp, Paper and Paperboard* and the emission intensity of this product group was considered in the analysis.

3. Data sources

For the empirical application, the following data sources were used:

- The data on CO_2 and non-CO_2 GHG emissions were obtained from the Satellite Atmospheric Emissions Accounts for Spain provided by the Spanish Institute of Statistics for the year 2003 (INE 2010a). The emission data were aggregated into 47 industries and total output factors are used to disaggregate them into 73 industries in order to be consistent with the EIO model. These data were used to derive vector ***b*** equation 2 and 3.
- The economic data on sectoral transactions come from the Supply and Use tables published by the Spanish Institute of Statistics for the same year 2003 (INE 2010b). The Supply and Use tables are disaggregated into 73 industries and 118 products and they were used to derive both the industry-by-industry and commodity-by-industry total requirement matrices necessary in equation 2 and 3 respectively.
- The data on the ad valorem tax ***t*** on industries were calculated from the Use table by dividing the Taxes less subsidies on products by the total sectorial

uses in basic prices. The values of ***t*** for commodity-by-industry base EIO model were then computed by multiplying industrial ***t*** by matrix ***D***.

- EcoInvent database (v. 2.02) and a detailed life cycle inventory data of a Spanish pulp mill compiled by González-García et al. (2009) were used to estimate the life cycle CO_2 and GHG emissions associated with the production of Kraft pulp bleached at plant in Spain. The inputs and outputs are scaled up to the total production of pulp for the year 2003.

4. Results and discussion

This section is concerned with the presentation of results from environmental tax calculations based on emission intensities (both CO_2 and GHG) derived from different methods described in the methodology section; namely EIO sectoral and product group approaches and LCA. First, the emission intensity of Kraft pulp production estimated by the application of conventional LCA is presented. A more detailed analysis on the sources of emissions and the share of each process are discussed. Secondly, the price variation that resulted from the introduction of environmental tax for all industries and products in general, and the pulp and paper sector in particular using the EIO models are examined. Finally, the comparison of results obtained from the LCA, EIO industry approach and EIO product approach is explained.

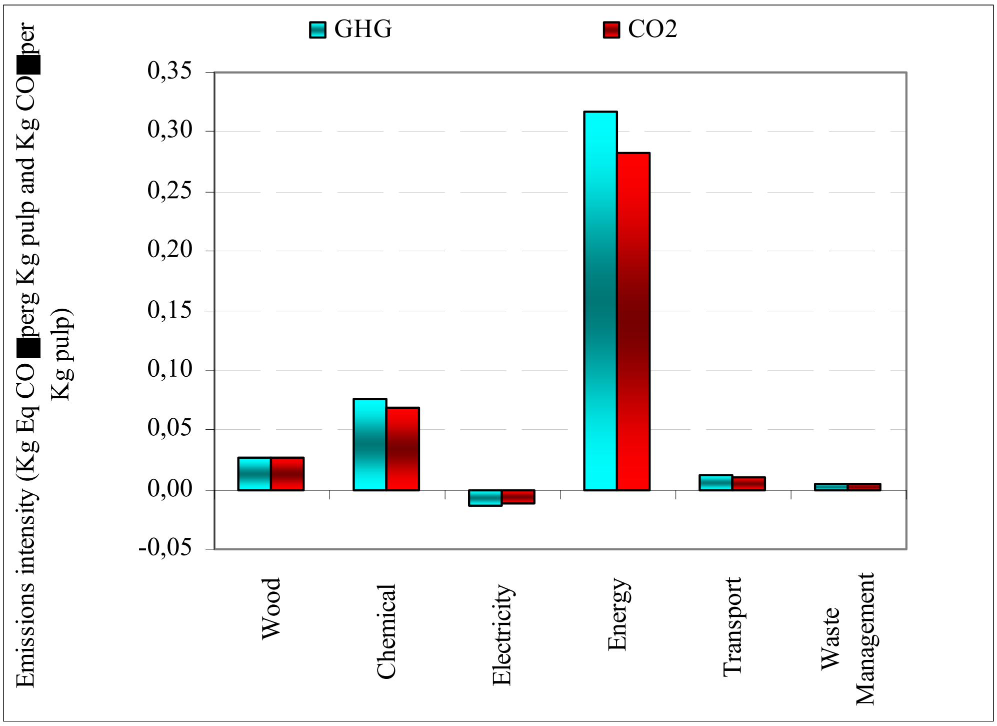


Figure 2 GHG and CO_2 emissions by life-cycle stage of Kraft pulp production

Figure 2 shows both the CO_2 and GHG emission intensity of Kraft pulp production using the LCA approach. The emissions are broken down per life cycle stage. Energy production is the process of highest impact, followed by the production and use of chemicals. As shown in Figure 2, the emissions from the electricity production stage are considered negative. This is due to the fact that the paper pulping process uses a cogeneration unit to generate energy from biomass waste, black liquor and fossil fuels in order to meet its energy requirement. The electricity surplus from the process goes to the national grid and results in an avoidance of emissions due to the saving of material and energy required to generate an equivalent amount of electricity sold to the grid.

There is a slight difference in the global GHG and CO_2 emissions. The GHG emissions are mainly driven by the CO_2 emission (more than 95% in all stages except energy and chemical production where CO_2 accounts for around 90%). In the case of energy production, the difference is mainly due to methane (CH_4) emission from the use of heavy fuel oil, resulting from incomplete-combustion or low-temperature combustion in the oil boiler during heat production. Energy production is majorly responsible for both CO_2 and GHG emissions, which accounts for 74 and 75% of the total emissions respectively. Chemical production and wood extraction are also important elements that have significant contributions, with the percentage share of chemical production being 18% in both CO_2 and GHG intensity. Wood extraction accounts for 6,5 and 7% of the total emissions in CO_2 and GHG, respectively. The total CO_2 and GHG emissions are estimated to be 382 g and 424 g Eq CO_2 per Kg of pulp production, respectively and the emission intensities per euro output are approximated to be 0,9 Kg CO_2 and 1 Kg CO_2 eq[v].

Although not so detailed and precise as LCA, EIO allows for a quicker screening of CO_2 and GHG emissions related to all the products and services within the Spanish economy. The results of the EIO models, both industry and product approaches are summarized in Table 1 and Table 2 respectively. Particularly, Table 1 below shows results from EIO model for the top 25 product groups that would be subjected to the highest environmental tax if they were levied based on their emission intensities (both CO_2 and GHG) per € output. As expected, the products most affected by the introduction of an environmental tax based on CO_2 emissions intensities, are the product groups 38, Cement, lime and plasters, with a

20,94% increase over the tax-exclusive price, and 13, Production and distribution of electricity, 8,90% increase of price. Cement, lime and plaster production are known as energy intensive processes, which result in high emission intensity both from the consumption of fuels and calcinations of limestone. Cement production alone accounts for 6,3 to 7,2% of global industrial energy use, with an average primary energy intensity of 4,4 gigajoules per tonne of production (IEA 2007).

The combined environmental and actual indirect taxes are mainly influenced by the environmental tax. This influence is especially visible in the case of product group 38, for which an environmental tax would increase their price by 24,89% compared to the 3,26% increase provoked by ordinary taxes. For product group 13, the combined tax rate is 7,12% due to an 8,90% environmental tax rate and 1,64% applied subsidies. These results show that the fiscal treatment of electricity does not point in the same direction as the environmental tax, and indeed implies that more subsidies on electricity and erroneous environmental evaluation will lead to a misleading conclusion. For example, electric cars are generally considered as environmentally friendly products with almost zero emissions, because the use of electricity as a fuel is usually considered as emission free. However, the production of electricity is highly polluting, especially in a country like Spain where the share of renewable energies in the national mix is low (28% from the total energy production in 2003)(RED, 2004).

Table 1. Comparison of taxes for top 25 CO_2 and GHG polluting product groups

Product Name	Code	CO_2			GHG		
		τ	t	t*	τ_1	t_1	t_1*
Cement, lime and plaster	38	20,94	3,26	24,89	21,06	3,26	25,01
Production and distribution of electricity	13	8,90	-1,64	7,12	9,11	-1,64	7,32
Other non-metallic products	41	4,12	1,00	5,16	4,19	1,00	5,22
Water transport	75	3,51	0,52	4,05	3,59	0,52	4,13
Production and distribution of gas	14	3,33	0,68	4,04	3,41	0,68	4,12
Coke, petroleum and nuclear fuel	12	1,95	2,71	4,71	1,99	2,71	4,75
Air transport	76	1,91	0,20	2,11	1,94	0,20	2,14
Glass and glass products	39	1,86	1,45	3,33	1,91	1,45	3,38
Land transport	73	1,52	11,04	12,73	1,57	11,04	12,78
Ceramic articles	40	1,46	1,12	2,60	1,51	1,12	2,65
Coal and lignite peat	6	1,45	2,07	3,55	2,68	2,07	4,80
Fish and other fishing products	5	1,45	0,65	2,11	1,50	0,65	2,16
Basic metal	42	1,35	0,56	1,92	1,41	0,56	1,98
Articles of paper and paperboard	30	1,20	0,50	1,70	1,27	0,50	1,78
Non-metallic non-energetic ores	11	1,01	2,95	3,99	1,07	2,95	4,05
Non-residential buildings	62	0,95	0,72	1,68	1,00	0,72	1,73
Civil engineering	63	0,94	0,76	1,71	0,98	0,76	1,75
Residential buildings	61	0,93	0,74	1,68	0,97	0,74	1,71
Renting services	64	0,87	0,93	1,81	0,91	0,93	1,84
Waters and soft drinks	22	0,86	-5,36	-4,55	1,20	-5,36	-4,23
Secondary raw materials	60	0,81	0,22	1,03	0,85	0,22	1,07
Railway transportation	71	0,79	0,52	1,31	0,81	0,52	1,34
Pulp, paper and paperboard	29	0,77	0,32	1,09	0,81	0,32	1,14
Basic metals	21	0,76	-4,82	-4,09	1,04	-4,82	-3,82
Agricultural and livestock services	3	0,76	-4,75	-4,03	2,87	-4,75	-2,02

If environmental taxes on CO_2 were applied to industries instead of products, from Table 2 it can be seen that these taxes would be higher and without differences between the products within the same sector; e.g. the Manufacture of pulp, paper and paper products (industry 21) is ranked as the 16th CO_2 polluting sector and in the industrial environmental taxes approach it would experience a 1,35% price increase of its products. However, in the commodity approach (Table 1), the same industry is split into two products: Pulp, paper and paperboard (product group 29) whose environmental tax would increase their price by 0,77% and Articles of paper and paperboard (product group 30) which would register a 1,20% increase of the price if an environmental tax on products is applied.

Table 2. Comparison of taxes for top 26 CO_2 and GHG polluting industries

Product Name	Code	CO_2			GHG		
		τ	t	t^*	τ_1	t_1	t_1^*
Manufacture of cement	25	23,62	3,66	28,15	23,74	3,66	28,28
Production and distribution of electricity	9	9,08	-1,69	7,24	9,29	-1,69	7,44
Manufacture of other non-metal	28	4,10	1,00	5,15	4,16	1,00	5,21
Water transport	48	3,63	0,51	4,16	3,71	0,51	4,24
Mining of metal ores	6	3,56	1,59	5,20	3,62	1,59	5,27
Manufacture of gas	10	3,34	0,68	4,04	3,42	0,68	4,12
Mining of coal and lignite	4	2,65	3,76	6,51	4,88	3,76	8,83
Air transport	49	2,57	0,26	2,84	2,61	0,26	2,88
Manufacture of glass	26	2,55	1,98	4,58	2,61	1,98	4,65
Manufacture of coke & petroleum	8	2,53	3,53	6,15	2,58	3,53	6,20
Fishing	3	2,20	0,98	3,20	2,27	0,98	3,27
Manufacture of basics metals	29	1,95	0,81	2,78	2,03	0,81	2,86
Extraction of petroleum and NG	5	1,74	1,68	3,46	1,85	1,68	3,56
Manufacture of ceramic products	27	1,63	1,23	2,87	1,68	1,23	2,93
Land transport	47	1,61	11,89	13,68	1,66	11,89	13,74
Manufacture of pulp & paper products	21	1,35	0,56	1,91	1,43	0,56	2,00
Other mining and quarrying	7	1,16	3,43	4,63	1,22	3,43	4,70
Manufacture of chemical products	23	1,11	0,60	1,72	1,42	0,60	2,03
Manufacture of textiles	17	0,94	-1,78	-0,86	1,09	-1,78	-0,72
Construction	40	0,93	0,74	1,68	0,97	0,74	1,71
Manufacture of beverages	15	0,89	-5,65	-4,81	1,22	-5,65	-4,50
Manufacture of dairy products	13	0,82	0,00	0,82	1,65	0,00	1,65
Recycling	39	0,81	0,22	1,03	0,85	0,22	1,07
Railway transport	46	0,80	0,53	1,33	0,82	0,53	1,36
Manufacture of meat products	12	0,78	-0,15	0,63	1,91	-0,15	1,75
Agriculture, livestock and hunting	1	0,78	-5,34	-4,61	3,06	-5,34	-2,45

The positions of highly emitting industries and products change when environmental tax is based on GHG emission intensities instead of CO_2 can also be seen in Table 1 and 2. Industries that show a significant change taking GHG into consideration are mining of coal and lignite; extraction of peat (4), agriculture, livestock and hunting (1) and the food sectors (12, 13 and 14). The inclusion of non-CO_2 GHG emissions increases the environmental tax of agriculture, livestock and hunting (1) sector by a factor of 4. The tax for mining of coal and lignite, the extraction of peat (4) and the food manufacturing sectors (12, 13 and 14) are increased by a factor of 1,84 and 2, respectively. This is mainly due to the emissions of CH_4 and N_2O. The main possible sources of CH_4 are from manure storage, particularly in anaerobic conditions and from enteric fermentation, especially in the case of ruminants. Similarly, N_2O are emitted due to the application of synthetic fertilizers and manure on soil as well as from crops residue applied on soil and from storing and handling of manures.

The Manufacture of pulp, paper and paper products (industry 21) and its product groups (29 and 30) are not affected by the inclusion of non-CO_2 GHG for environmental tax calculation. The percentage increase of the tax from CO_2 to GHG is only 6% and it is negligible compared with industries like Mining of coal and lignite; agriculture, livestock and hunting; and food production industries.

The different approaches for implementing an environmental tax were then evaluated and compared. The commodity approach has the advantage of differentiating between 118 commodities/products, whilst the sectorial aggregation includes 73 sectors. This would suggest the use of the commodity approach. However, when comparing the emissions intensities in the two EIO approaches with LCA results, a much more detailed and specific environmental evaluation, it is not so clear which approach works better. Specifically, for the sector of paper and paper products, we obtained the following results:

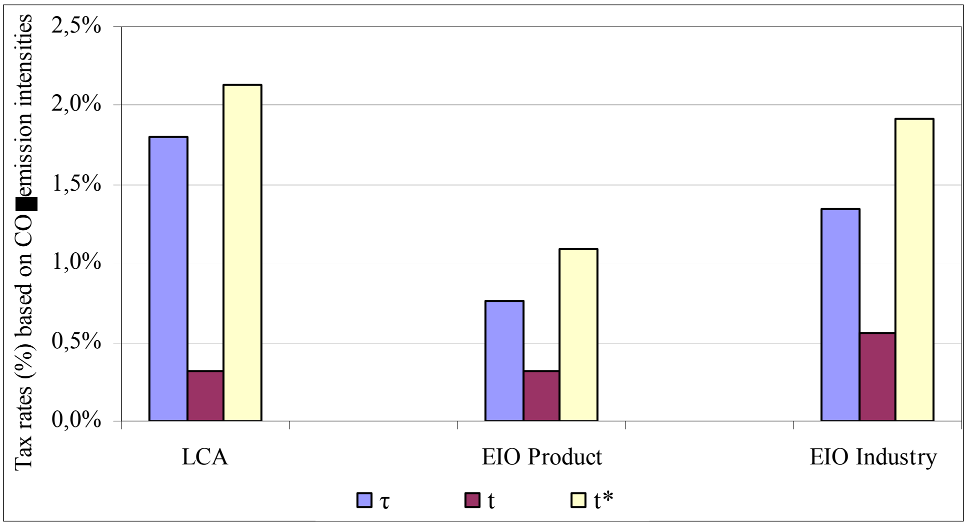
Table 3. Comparison of Emission Intensity from EIO industry, product and LCA approaches

Method	Emission Intensity (kg $C0_2$/€ or kg eq CO_2/€)		Industry or Product
	CO_2	GHG	
EIO, Industry	0,67	0,72	Manufacture of pulp, paper and paper products
EIO, Product	0,38	0,41	Pulp, paper and paperboard
LCA	0,90	1,00	Kraft pulp production

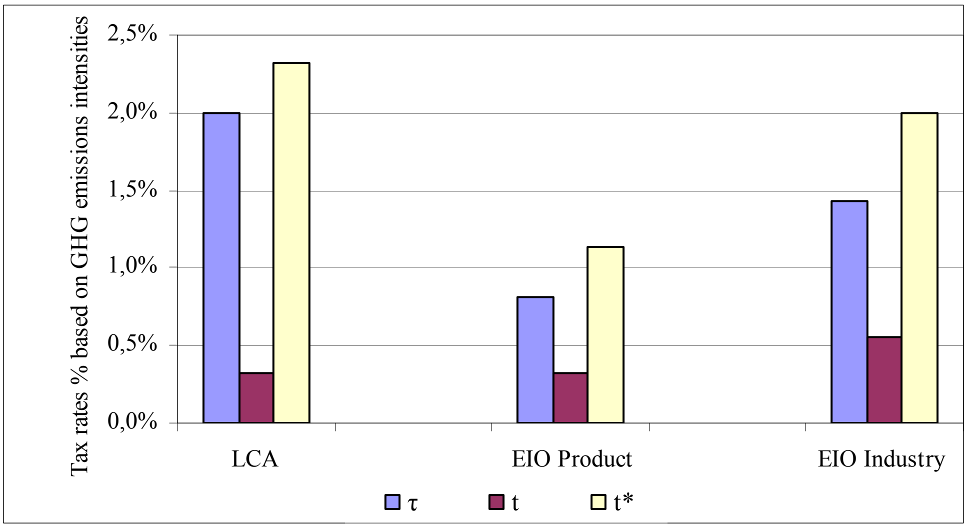
Table 3 shows that the LCA results are greater than both IO approaches, but much more product-specific; e.g. it evaluates the CO_2 and GHG emissions per kg of paper pulp produced by the Kraft process (the one mainly used in Spain) and not per aggregated product group “Pulp, paper and paperboard” or even more sector aggregated “Manufacture of pulp, paper and paper products.” Furthermore, LCA uses specific process data and material flows between processes, instead of monetary flows.

If LCA results were to be used as base for calculating environmental taxes instead of EIO approaches, then the results in Figure 3 would be obtained. Taking into consideration that we do not have the indirect taxes that are applied specifically to the paper pulp obtained through the Kraft process, we assume them to be equal to those applied to the product group 29 (Pulp, paper and paperboard - see Table 1).

Following the results presented in Figure 3, as LCA estimates a higher CO_2 and GHG emission intensity than the EIO product group or sectoral approach, the environmental tax (**τ**) based on LCA will be also higher than both EIO approaches.



(a)



(b)

Figure 3 Comparison of tax rates for pulp product and paper industry based on CO_2 (a) and GHG (b) emission intensities from LCA, EIO industry and EIO product approaches.

The tax comparison result between CO_2 and GHG emissions for pulp and paper sector shows that inclusion of non-CO_2 GHG emissions in the tax calculation has almost no effect among product group and industry for the EIO approach and the LCA, as the relative contribution of non-CO_2 GHG emissions to the total GHG emissions of the sector is very small, being only 4,8%. However, it is important to take this into account for sectors with a high potential for non-CO_2 GHG emissions, for example agriculture, livestock and hunting where the contribution of non-CO_2 GHG emission is around 83% of the total GHG emissions of the sector. Methane gas (CH_4) with a 23 times higher global warming potential than CO_2 takes the largest share. Agricultural products serve as inputs to food industries, making the manufacturing sectors of dairy products, meat products and other food products indirect contributors to non-GHG emissions. Therefore, the environmental tax policy for such sectors should include all GHG emissions, as tax based only CO_2 emissions would not reflect the high potential impacts of non-CO_2 GHG emissions.

5. Conclusion

Our results show that emission intensity and the associated environmental tax are higher in the LCA approach than both EIO approaches, but they are all comparable. LCA approach is a more product specific than EIO and gives a more precise estimation of emissions and environmental tax. However, being time and labour intensive to cover all products and services in a national economy, in terms of operationally, it might not be the best approach to calculate product or industry emission intensities on which to base an economy wide taxation. On the other side, despite the fact that they usually lose the product specificity, the EIO models can provide a comparatively detailed and holistic picture of both direct and indirect environmental impacts associated with sectoral production, on which the environmental tax is based. Nevertheless, it is important to be aware of the fact that environmental taxes based on EIO models are not appropriate to reflect long-term scenarios. As the intrinsic assumption of the EIO models is that of fixed inputs to production. Based on this assumption it is not possible to reflect changes in the productive structure of the country in question, nor to reflect improvements in technologies, both increased efficiency and a switch to less emissions intensive inputs. Consequently, the efforts of industries which shift from consumption of high emission intensity to low emission intensity input to production (e.g. a shift from virgin pulp to recycled waste paper) would not be considered. Thus, the results presented only reflect the short-term environmental tax effect on price.

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References

Asociación Española de Fabricantes de Pasta, Papel y Cartón (ASPAPEL), 2009. Sustainability report. ASPAPEL, Madrid

Bullard, C. W., Penner, P. S., Pilati, D. A., 1978. Net energy analysis: Handbook for combining process and input-output analysis. Resources and Energy, 1(3), 267-313.

Carrere, R., Lohmann, L., 1996. Pulping the South: Industrial Tree Plantations and the World Paper Economy, Zed Books Limited.

Clarkson, R. Deyes, K., 2002. Estimating the Social Cost of Carbon Emissions. The Public Enquiry Unit-HM Treasury, London, Working Paper 140.

Committee on Climate Change (CCC), 2008. Building a low-carbon economy - the UK's contribution to tackling climate change. The Stationary Office (TSO), London.

Creedy, J., Martin, C., 2000. Carbon Taxation, Fuel Substitution and Welfare in Australia. Australian Economic Review, 33(1), 32-48.

Creedy, J., Sleeman, C., 2006. Carbon taxation, prices and welfare in New Zealand. Ecological Economics, 57(3), 333-345.

Das, T. K., Houtman, C., 2004. Evaluating chemical-, mechanical-, and bio-pulping processes and their sustainability characterization using life-cycle assessment. Environmental Progress, 23(4), 347-357.

den Elzen, M., Meinshausen, M., van Vuuren, D., 2007. Multi-gas emission envelopes to meet greenhouse gas concentration targets: Costs versus certainty of limiting temperature increase. Global Environmental Change, 17 (2), 260-280

European Commission (EC), 2001. Integrated Pollution Prevention and Control (IPPC), Reference Document on Best Available Techniques in the Pulp and Paper Industry. Institute for Prospective Technological Studies, Seville

European Commission (EC), 2008. The EU emissions trading scheme, EU action against climate change. European commission, Directorate-General for the Environment, Belgium

European Environment Agency (EEA), 1996. Environmental tax implementation and environmental effectiveness. Environmental Issues Series No. 1, Copenhagen.

Fullerton, D., Leicester, A., Smith, S., 2008. “Environmental Taxes” Dimensions of Tax Design. Ed. Institute for Fiscal Studies (IFS). Oxford University Press, Available at:

http://works.bepress.com/don_fullerton/37

González-García, S., Hospido, A., Moreira, M. T., Romero, J., Feijoo, G., 2009. Environmental impact assessment of total chlorine free pulp from Eucalyptus globulus in Spain. Journal of Cleaner Production, 17(11), 1010-1016.

Guinée, J. B., Gorée, M., Heijungs, R., Huppes, G., Kleijn, R., de Koning, A., van Oers, L., Wegener Sleeswijk, A., Suh, S., Udo de Haes, H. A., de Bruijn, H., van Duin, R., Huijbregts, M. A. J., 2002. Handbook on life cycle assessment - operational guide to the ISO standards. Kluwer Academic Publishers, Dordrecht.

International Energy Agency (IEA), 2007. Tracking Industrial Energy Efficiency and CO_2 Emissions. Head of Communication and Information Office, Paris.

Instituto Nacional de Estadística (INE), 2010a. Atmospheric emissions satellite accounts. 1990 and 1995-2003 series. Madrid

Instituto Nacional de Estadística (INE), 2010b. Spanish National Accounts, Base 2000. Madrid

IPCC, 2007. Summary for Policymakers. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

ISO, 2006a. ISO 14040- Environmental management — life cycle assessment — principles and framework. The International Organization for Standardization.

ISO, 2006b. ISO 14064-1- Greenhouse gases – Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals. The International Organization for Standardization.

Heijungs, R., 1994. A generic method for the identification of options for cleaner products. Ecological Economics, 10(1), 69-81.

Hischier, R., 2007. Life Cycle Inventories of Packagings and Graphical Papers. ecoinvent-Report No. 11, Swiss Centre for Life Cycle Inventories, Dübendorf

Hourcade, J.C., Shukla, P.R., 2001. Global, regional and national costs and ancillary benefits of mitigation. In: Metz, B., Davidson, O., Swart, R., Pan, J. (Eds.), Climate Change 2001: Mitigation; Contribution of Working Group III to the Third Assessment Report of the IPCC, Cambridge

University Press, Cambridge, UK.

Jaffe, A. B., Stavins, R.N., 1995. Dynamic Incentives of Environmental Regulation: The Effects of Alternative Policy Instruments on Technology Diffusion. Journal of Environmental Economics and Management, 29, S43-S63

Lopes, E., Dias, A., Arroja, L., Capela, I., Pereira, F., 2003. Application of life cycle assessment to the Portuguese pulp and paper industry. Journal of Cleaner Production, 11(1), 51-59.

Lenzen, M., 2000. Errors in Conventional and Input-Output-based Life-Cycle Inventories. Journal of Industrial Ecology, 4(4), 127-148.

Matthews, H. S., Hendrickson, C. T., Weber, C. L., 2008. The Importance of Carbon Footprint Estimation Boundaries. Environmental Science & Technology, 42(16), 5839-5842.

Miller, R. E., and Blair, P. D., 2009. Input-Output Analysis: Foundations and Extensions. Cambridge University Press, New York.

Ministerio de Medio Ambiente y Medio Rural y Marino (MARM), 2006. PLAN NACIONAL DE ASIGNACIÓN DE DERECHOS DE EMISIÓN 2008-2012 (in spanish).

Organization for Economic Cooperation and Development (OECD), 2008a. Environmental Outlook to 2030. Paris.

Organization for Economic Cooperation and Development (OECD), 2008b. OECD Environmental Data Compendium 2006-2008. Paris

Parry, I., Harrington, W., Nelson, P.K., Safirova, E., Mason, D., Gillingham, K., 2003. Welfare and Distributional Effects of Road Pricing Schemes for Metropolitan Washington, DC. Resources for the Future.

Pterba, J.M., 1993. Global warming policy: A public finance perspective. Journal of Economic Perspective, 7(4), 1167 - 1182

Rao, S., Riahi, K., 2006. The role of non-CO_2 greenhouse gases in climate change mitigation: long-term scenarios for the 21^{st} century. Energy Journal, International Association for Energy Economics, Special issue I, 177 -200

Red Eléctrica de España (RED), El sistema eléctrico español 2003 http://www.ree.es/

Stern, N., 2006. The Economics of Climate Change, HM Treasury, London.

Stone, R., 1961. Input-Output and National Account. Office of European Economic Cooperation, Paris.

Suh, S., 2004. Functions, commodities and environmental impacts in an ecological-economic model. Ecological Economics, 48(4), 451-467.

Szabó, L., Soria, A., Forsström, J., Keränen, J. T., Hytönen, E., 2009. A world model of the pulp and paper industry: Demand, energy consumption and emission scenarios to 2030. Environmental Science & Policy, 12(3), 257-269.

United Nations (UN), 1968. A System of National Accounts. Studies in Methods. Series F, No. 2, rev.3, UN, Department of Economic and Social Affairs, New York.

United Nations (UN), 1992. Earth Summit, Agenda 21, UN Conference on Environmental Development, the United Nations programme of action from Rio de Janeiro. UN, Division for Sustainable Development.

United Nations (UN), 2002. United Nations General Assembly, World Summit on Sustainable Development: Plan of Implementation. UN, Division for Sustainable Development, New York.

United Nations (UN), 2011. UN News Centre. http://www.un.org/

United Nations Framework Convention on Climate Change (UNFCCC), 1998. Kyoto Protocol to the United Nations Framework Convention on Climate Change. UNFCCC, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK.

Worrell, E., Neelis, M., Price, L., Galitsky, C., Zhou, N., 2008. World Best Practice Energy Intensity Values for Selected Industrial Sectors. Berkeley, CA: Lawrence Berkeley National Laboratory.

Yohe, G. W., Lasco, R. D., Ahmad, Q. K., Arnell, N. W., Cohen, S. J., Hope, C., Janetos, A. C., Perez, R. T., 2007. Perspectives on climate change and sustainability. Climate Change 2007: Impacts, Adaptation and Vulnerability.

Footnotes

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[i] The six greenhouse gases that are covered by the Kyoto Protocol are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), HFCs, PFCs and sulphur hexafluoride (SF_6) (UNFCCC, 1998). Only these emissions are covered in this study.

[ii] According to ISO 14040 the term “product” is defined as both “goods” (e.g. consumer goods, intermediate goods) and “services” (ISO, 2006a).

[iii] Functional unit (FU): According to ISO 14040, a functional unit is defined as “the quantified performance of a product system for use as a reference unit.”(ISO, 2006a)

[iv] Partial equilibrium is “The method of analysis dealing with some part of the economy, deliberately ignoring possible implications of changes in this part for what happens in the rest of the economy. In studying the effects of changes in the supply and demand for a particular good on its equilibrium price and quantity a partial equilibrium analysis ignores changes in the rest of the economy, due for example to consequent changes in income distribution. This is contrasted with general-equilibrium analysis, in which the repercussions of changes in any one market throughout the rest of the economy are taken into account. General equilibrium models are necessarily either much more generalized or much more complex than partial equilibrium models. Partial equilibrium analysis is most useful when events in the sector studied have only small effects in the rest of the economy.” The Oxford Dictionary of Economics

[v] Considering the average producer price of paper pulp in Spain in 2003 was 425€/ton.