Comparison of life cycle inventory (LCI) methods for carbon footprint calculation:-the case of pulp and paper sector in Spain

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Abstract. Greenhouse gases (GHG) emissions induced by human activities are the major causes of climate change. The unsustainable production and consumption patterns are the main driver behind it. Despite being on the policy agenda since the first earth summit in 1992, the reduction of emissions caused by production and consumption is too slow as most policy instruments are usually created without regard to the environmental impact of individual agents and productive sectors. Imposing an environmental tax which reflects the true costs of products and services could be a way to influence both producers and consumers to alter their behaviours and to move a step forward to sustainability. Environmental tax should be proportional to products' carbon footprint and should reveal their true costs by internalizing all the external loads to the environment and to the society that are not included in their price. The main challenge is how to estimate the carbon footprint of each product or service in the economy. There are different methods to assess carbon footprint, such as process based life cycle analysis (LCA), Environmental Input-Output (EIO) and Hybrid IOLCA models. Each method has its own strength and weakness compared with others considering criteria of data requirements, source data uncertainty, upstream and downstream system boundary consideration, time and labour intensity, and so on. In this paper we investigate the most relevant approach from environmental tax introduction point of view. A product of pulp and paper industry of the Spanish economy is analyzed using different methods (LCA, EIO product group approach, EIO industrial approach, tiered hybrid IOLCA and IO-based hybrid) and results are compared.

1. Introduction

There is an increasing concern of climate change around the globe, as different scientific research revealed the unequivocalness of global warming and the urgency need of global response in GHG reduction [1]. Unsustainable consumption and production patterns with population growth and socio-economic development are among the major driving forces behind the anthropogenic GHG emissions. Environmental taxation is one of the economic instruments which can play an important role in moving the world a step forward to sustainability by reducing human related emissions due to production and consumption.

The principle behind an environmental tax is that a defined levy is introduced on environmentally polluting products 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 into the price, the introduction of an environmental tax would raise the prices of polluting goods and services and it would decrease the 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, the distributional effects and the global competitiveness are the main drawbacks of environmental taxes, issues which need attention in order to make such instruments worthwhile [2].

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 arise from its production (e.g. emissions released during the production of a car), use (e.g. emissions released by burning the fuel in a car), but also before its production (e.g. from producing the inputs necessary to produce the final product "car", e.g. wheels, screen, etc.) and after its use (continuing with our example, dismantling the car and recycling its components and/or disposing it in a landfill). The first question that arises is which of these emissions we should consider for 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, taking into account the extraction of raw materials from the environment, their processing to enter as inputs in the production process, the use of the product and its final disposal? Clearly, different boundaries of emissions assessment will lead to huge discrepancy in results, implying different policy measures (e.g. different environmental taxes). In this paper, we investigate the relevancy of different life cycle inventory methods to determine carbon footprint of products and services for environmental tax application. The variation of an environmental tax which results from the choice of methodologies and its policy implication are analyzed. Paper product from paper and pulp industry of the Spanish economy has been chosen as a case study. Environmental input-output (EIO), the conventional Life Cycle Assessment (LCA) and, Hybrid IOLCA models are used as methodological tools to calculate the carbon footprint of the product, which is then translated into environmental tax.

2. Methodology

The ever growing concern of climate change and a response to reduce the anthropogenic GHG need strong environmental policies that support decision-makers to take action. These have motivated and contributed a lot for the development and improvement of already existing methods for assessing the environmental impacts of human activates. LCA, EIO, and more recently hybrid-IOLCA models are the main approaches currently used to estimate emissions intensity of products and services [3]. In our case we used LCA, EIO, tiered hybrid and IO-based hybrid models to estimate carbon footprint both at product, product group and industrial level.

EIO model is a top-down approach used to account for resource flow and environmental impacts based on input-output tables (first developed by Leontief in the 1930s). EIO model uses generic data at national level and calculates the GHG emissions released by all the economy to produce the total output of a given industry for final demand (from vector *m* in the equation below):

$$m = b(I - A)^{-1} y \qquad (1)$$

$(I\text{-}A)^{-1}$ is the Leontief's inverse matrix, where I is identity matrix and A is the matrix of technical coefficients. Each element a_{ij} of matrix A measures the flow from industry i required to produce 1€ output of industry j. b is sectoral emissions vector, which measures the amount of GHG released to produce 1€ output for each industry i. y is a vector of final demand.

Process-based LCA is a bottom-up approach in which main resource inputs and associated GHG emissions of the major production process and some important inputs from upstream processes into main processes are considered. The GHG emissions $\tilde{m}$ released to produce a given functional unit f are calculated as:

$$\tilde{m} = \tilde{b}\tilde{A}^{-1} f \qquad (2)$$

Where $\tilde{b}$ is the matrix of GHG emissions per unit flow of mass and energy from one process to another, $\tilde{A}$ is technology matrix, in which each element represents inflow and outflow of energy or material from one process to another.

Generally both conventional LCA and EIO approaches have their advantages and disadvantages one over the other. LCA provides more detailed and accurate analysis on a specific product level. But it is limited to cover all upstream processes in high degree of detaility since it is time and resource intensive to include all upstream inputs. On the other hand, EIO model can provide the holistic view of economic interdependence of industries and it is superior instrument to model carbon footprint at industrial level. The system incompleteness of conventional LCA and lack of process specificity of EIO could be overcome by combing both approaches, which is referred as Hybrid IO-LCA [4]. There are different ways of linking process based LCA and EIO approaches, namely tiered hybrid, input-output based LCA and integrated hybrid models [3].

Tiered hybrid is simple combination of process based LCA and EIO. In this case, all foreground systems of productions, consumption and end-off life stages of a product are modelled using conventional LCA data and the remaining background systems are modelled using EIO data in an effort to overcome system incompleteness problem of LCA due to upstream cut-off [3-6]. In equation form, this is written:

$$m_{Tiered} = \tilde{m} + m \qquad (3)$$

where m_{Tiered} is carbon footprint of products or services.

Input-Output based hybrid model is another way of linking LCA and EIO. This approach is based on disaggregation of an industry in IO table, for detail methodological approach refer model II of Joshi [6]. When detailed economic data on purchases and sales are available for specific production process or service, then its corresponding industry could be disaggregated into two. For example, carbon footprint associated with the paper production of a given company could be estimated by splitting the main industry, the manufacture of pulp, paper and paper products (industry 21 in the Spanish IO table) into 21 and 21a, where 21a stands for the footprint of the paper production only. Fig.1 below shows the scheme of disaggregation of the manufacture of pulp, paper and paper products.

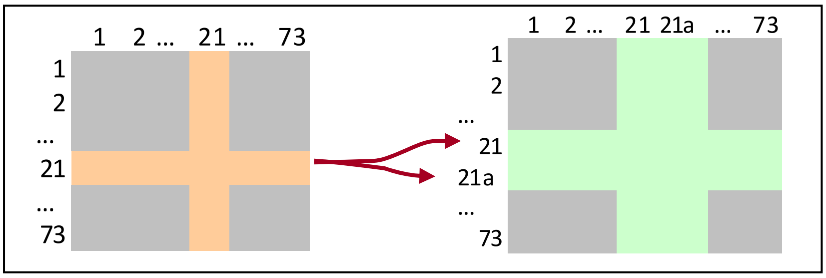

Fig.1: The scheme of disaggregation of the manufacture of pulp, paper and paper products (industry 21 in the Spanish IO table)

The environmental tax based on the carbon footprint of products, product groups and industries, is then calculated using the equation below:

$$tao = \varphi C \qquad (4)$$

C is GHG intensity (from vectors *m*, $\tilde{m}$ and m_{Tiered} in equations 1, 2 and 3 respectively) *and* φ is the environmental tax expressed in €/t CO_2. Since environmental tax is linked to economic distortions and inefficiencies, φ is usually estimated by considering the social cost as a marginal cost of emitting one extra ton of CO_2. However, such estimations are highly uncertain due to uncertainties in climate sensitivity, response lags, discount rate consideration, the treatment of equity, the valuation of economic and non-economic impacts and the treatment of possible catastrophic losses as explained by *Yohe, G.W., et al.* [7]. Therefore, we consider the tradable permit price of 20€ per ton of CO_2, as it is estimated to vary between 5–60 € per ton of CO_2 [8].

Once the tax is determined, the effective tax rate, which reflects the effect of environmental tax introduction on the final price, can be assessed. The effective tax rate is defined as a percentage increase of tax-exclusive price p_0 after the addition of an indirect tax, *t*, and an environmental tax, *tao* [9].

The price before the introduction of environmental tax is defined as a function of tax-exclusive price p_0 and ad valorem tax *t*:

$$p_1 = p_0(1+t) \tag{5}$$

The new price after the introduction of CO_2 tax will be:

$$p_2 = p_1(1+tao) \tag{6}$$

Therefore, the effective tax rate (t^*) is then expressed as:

$$t^* = t + tao(1+t) \tag{7}$$

3. Data

For the empirical application, the following data sources have been used:

1) Data on CO_2 and non-CO_2 GHG emissions are obtained from the Satellite Atmospheric Emissions Accounts for Spain provided by the Spanish Institute of Statistics for the year 2007. The emissions data come aggregated into 20 industries and 11 service sectors. Total output factors are used to disaggregate them into 73 industries in order to be consistent with the IO table. These data are used to derive vector *b* in equation 1 and 3.
2) Economic data on industrial transactions come from the Supply and Use tables published by the Spanish Institute of Statistics for the same year 2007. The Supply and Use tables come disaggregated into 73 industries and 118 product groups and they are used to derive the 73-industry by 73-industry table necessary in equation 1 and 3.
3) Life cycle inventory data and annual purchase and sale information for the year 2010 are obtained from a tissue paper producer in Spain. These data are

translated into 2007 prices using consumer and industry price indexes from the Spanish Institute of Statistics.

4) EcoInvent database (v. 2.1) are also used in estimating carbon footprint of tissue papers of the company.

4. Results and discussion

The main aim of this paper is to discuss the differences in the magnitude of environmental taxes on GHG if they are calculated based on different approaches. In particular we investigate the use of LCA, EIO and two hybrid IOLCA models, namely tiered hybrid and IO-based hybrid.

Fig.2 represents the results we obtained if the environmental tax would be calculated based on EIO product group approach by applying equation 1. As expected, the products most affected by the introduction of an environmental tax on GHG emissions are the product groups Cement, lime and plasters, with a 20.94% increase over the tax-exclusive price, and Production and distribution of electricity, 8.90% increase of price.

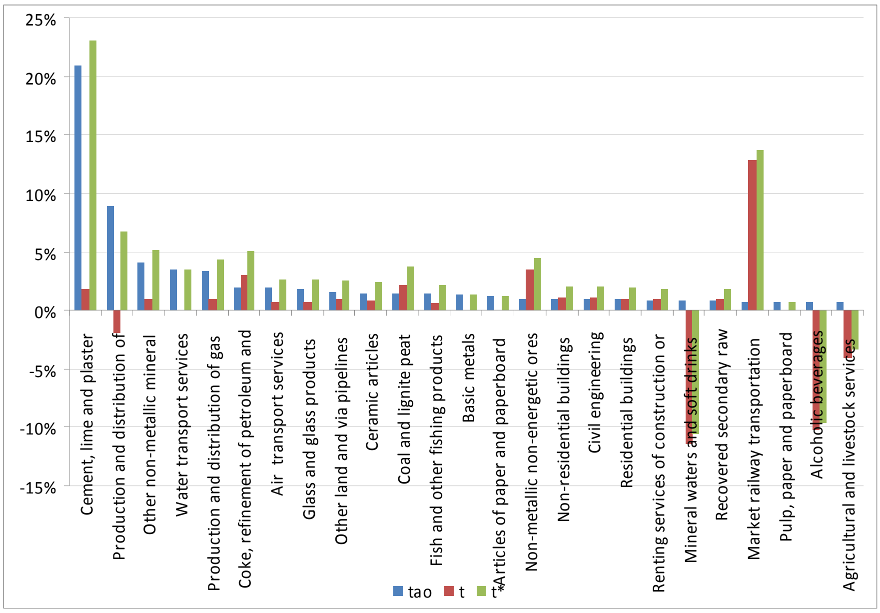

Fig.2: Comparison of taxes for top 25 GHG polluting product groups

The combined environmental and actual indirect taxes is mainly influenced by the environmental tax. This influence is especially visible in the case of the product groups Cement, lime and plasters, for which an environmental tax would increase their price by 23.12% compared to the 1.8% increase provoked by ordinary taxes. In the case of production and distribution of electricity, the combined tax rate is of 6.78% due to 8.90% environmental tax rate and 1.95% applied subsidies.

If environmental taxes on GHG emissions would be distributed on industries instead of on product groups, the industries most affected by the introduction of an environmental tax are the Manufacture of cement, lime and plaster, Production and distribution of electricity and the Manufacture of other non-metallic mineral products (Fig.3). For the Manufacture of cement, lime and plaster, the prices of its products would increase by a 24% if the tax would be applied. However, in this approach it is not possible to differentiate between the different environmental impacts of the products within the same industries; e.g. the Manufacture of pulp, paper and paper products is ranked as the 16th GHG polluting industries and in the industrial environmental taxes approach it would experience a 1.35% price increase of its products. However, in the product group approach (Fig.2), the same industry is split into two products: Pulp, paper and paperboard, whose environmental tax would increase their price by 0.77% and Articles of paper and paperboard, which would register a 1.20% increase of the price if environmental tax on products is applied.

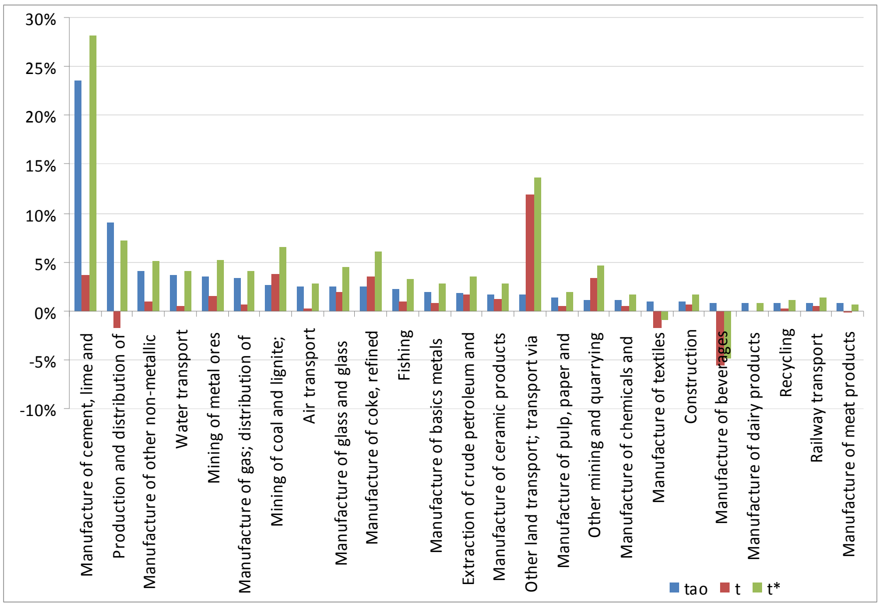

Fig. 3: Comparison of taxes for top 25 GHG emitting industries

Then the question is: which of the approaches is the best for establishing an environmental tax? The product group approach has the advantage of differentiating between 118 products; meanwhile the industry aggregation is up to

73 sectors. This would suggest using better using the commodity approach. However, when comparing the emissions intensities in the two IO approaches with LCA and hybrid IOLCA results, it is not so clear which approach works better. Specifically, based on real data from the tissue producer we obtain the following results (Table 3):

Tab.1: Comparison of EIO, LCA and Hybrid approaches

Approaches	Emissions Intensities	Industries, product groups and product
EIO industry approach	0.67 $kgCO_2$/€	Manufacture of pulp, paper and paper products
EIO commodity approach	0.38 $kgCO_2$/€	Pulp, paper and paperboard
	0.60 $kgCO_2$/€	Articles of paper and paperboard
LCA	0.29 $kgCO_2$/€	Tissue product
Tiered hybrid IOLCA	0.57 $kgCO_2$/€	Tissue producer and EIO commodity approach
IO-based hybrid IOLCA	2.52 $kgCO_2$/€	Tissue producer and EIO commodity approach

To calculate the LCA and hybrid IOLCA results, we considered the following boundaries between the LCA and the IO part:

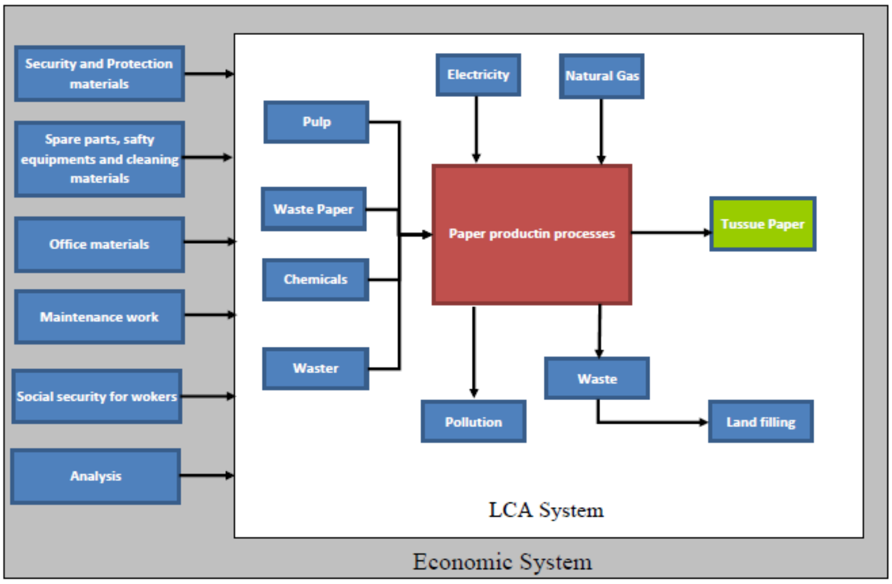

Fig. 4: Simplified flow diagram that defines the system boundaries of tissue paper production for tiered hybrid approach

In the tiered hybrid approach we estimated emissions from the LCA using the physical flows data obtained from the tissue producer and the service inputs that come from the economy. In the case of IO-based hybrid approach we used only the financial and emissions data of the producer.

The LCA results are closer to the EIO product group approach and smaller than both IO approaches, but much more product-specific; e.g. it evaluates the carbon footprint per kg of paper produced by the specific tissue producer and not per aggregated product group “Pulp, paper and paperboard” or even more sector aggregated “pulp, paper and paper products”. IO-based approach over estimates the carbon footprint of tissue production. This is because the financial data from the company are too aggregated, which results in miss allocation of input and output to industries.

The differences in environmental taxes based on the different approaches presented above are:

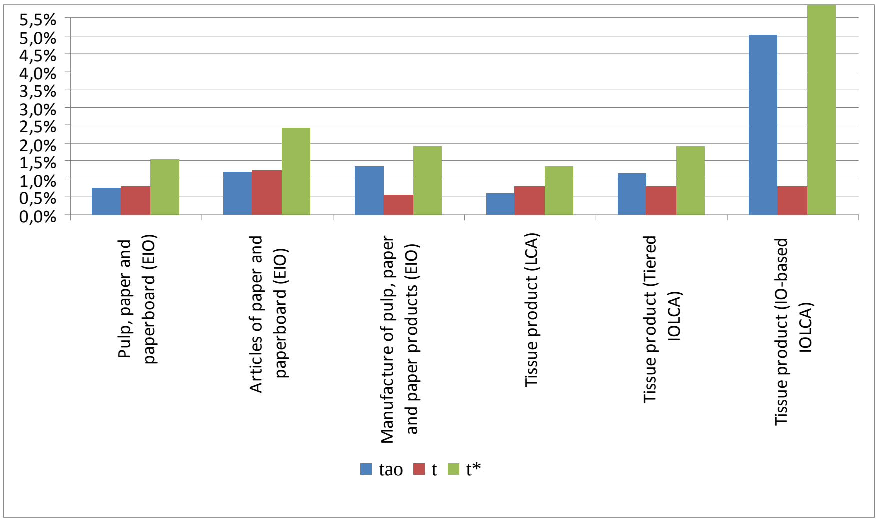

Fig. 5: Comparison of environmental taxes based on EIO, LCA and Hybrid approaches

Following the results presented in Fig.5, as LCA estimates smaller GHG emissions intensity than both EIO and Hybrid approaches, the environmental tax (*tao*) based on LCA will also be smaller than both EIO and hybrid approaches. However, as the indirect taxes per product are smaller, the combined environmental-indirect tax turns out to have a value between both approaches.

As LCA is the most product/service-specific, probably it is the best approach to calculate the emission intensities of products and services. However, given the availability of data and time to perform a LCA for each product/service, the best proxy would be given by a hybrid IOLCA which would use LCA-calculated emission intensities for all the available products and IO-calculated data, commodity approach, for the rest.

5. Acknowledgements

This work has been funded by the Spanish Ministerio de Educación y Cultura (grant SEJ2007-66318) and the Generalitat de Catalunya (grants SGR2009-322 and 2009SGR-230). We would also like to acknowledge the Department of Chemical Engineering of Universitat Rovira i Virgili for providing a PhD fund to carry out this project.

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