Carbon storage in HWP. Accounting for Spanish particleboard and fiberboard

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Abstract

Aim of study: The study quantifies carbon stock in particleboard and fibreboard, for the period 1990-2006. It is the first accounting made for the Spanish wood industry using industrial accurate data and it could be comparable to other European studies.

Area of study: Spain.

Material and methods: A comparison of the three different approaches (Stock Change Approach, Production Approach, Atmospheric Flow Approach) of the 2006 Intergovernmental Panel on Climate Change Guidelines for National Greenhouse Gas (GHG). Due to the complexity derived from the amount of input variables and the recurrence of the formulas, the Montecarlo simulation method was chosen to compare results.

Main results: Between 1990-2006 the carbon stock of the Spanish panel industry has been growing steadily, reaching around 1,000 Gg C in all three approaches studied. During the period 1990-2002, the Stock Change Approach is the one which provides a higher carbon stock accounting. However, since 2002 the Production Approach is the one which presents higher values of carbon stock.

Research highlights: The main result of the study shows the important role of carbon stock which play the Spanish wood based panel industry during the period analysed. The results highlight the economic and environmental importance of carbon stock stored in such wood products, as well as its remarkable increase during the study period. They also highlight the importance of good practices such as cascade use of wood resources as well as the need for properly coordination between climate change and forest policies.

Key words: climate change; emissions trading system; national greenhouse gas inventories; approach; Monte Carlo; recycled wood; cascade use.

Introduction

Under the name of Harvested Wood Products (HWP) reference is made to all wood material that leaves the harvest area, and is used for producing commodities like furniture, doors, flooring, packaging, paper products or others. The harvested wastes that don't leave the forest are accounted as dead organic material and their emissions are not taken into account in this study, because they are already analyzed under forest evaluation (Skog and Nicholson, 1998; IPCC, 2006).

The HWP can't be considered as carbon sinks, because a direct CO_2 flow doesn't exist from the atmosphere to them. However, they behave as temporal storage of carbon, because they lock the carbon from the wood of the forest, delaying its emission to the atmosphere depending on its lifetime and the decay process of the product (UNECE/FAO, 2008; Bowyer *et al.*, 2010).

Although HWP have been in the international agenda from the Plenary Meeting of the Intergovernmental Panel on Climate Change (IPCC) held in Geneva in 1996, it hasn't been until 2006 when IPCC has invited

Abbreviations used: HWP, harvested wood products; IPCC, intergovernmental panel on climate change; GHG, greenhouse gases.

the Parties to inform voluntary about HWP in their national inventories. Currently, after the Conference of the Parties held in Durban in 2011 (COP17/CMP7) that accounting of HWP is compulsory for those countries which had signed the agreement for the second period of Kyoto Protocol (2013-2020).

Another key step in the evolution of this kind of studies took place in IPCC experts meeting held in Dakar in 1998, where three new methodological approaches were defined. These methods, used in the calculations of this study, introduced new concepts apart from the existing default approach till that moment, which considers that all carbon content in wood returns to the atmosphere at the moment of the forest harvesting by instant oxidation (Brown *et al.*, 1999). In this sense, the carbon stock in HWP has been widely analyzed and studied by different researchers of numerous countries and they have accounted in different studies (Pingoud *et al.*, 1996; Flugsrud *et al.*, 2001; Poker *et al.*, 2002; Dias *et al.*, 2005; FOEN, 2007; Canals, 2010).

Although wood products alone are not a solution to the problem of the concentration of greenhouse gases (GHG) in the atmosphere, its role should not be ignored in the retention of these and, therefore, the desirability of HWP accounting in national balances emission (Stern, 2007; COM (2012)94 final). Moreover, it's convenient to underline the positive consequences that the accounting of carbon storage in HWP has in forest management, production or trade of wood products. Thus, it may give a new added value to the forest industry. It's a traditional sector whose sustainability depends increasingly on new sources of competitiveness and proper valuation of its products (Aulí, 2002; Hansen, 2006; Voces *et al.*, 2008).

The main objective of this work is the accounting of carbon stocked by the Spanish panelboard industry, particle and fiberboard, following the 2006 IPCC Guidelines for the national GHG inventories. Since it aims to develop a country-specific approach, consistent with Tier 3 methods recommended by the IPCC, this analysis focuses on the mentioned sector, due to the existence of an accurate and reliable database. Furthermore its election is justified by its backbone role in the whole HWP production chain or the high consumption rate of recycled wood in this industry. Finally, it is appropriate to emphasize the novelty of this work applied to the Spanish forest industry, thus promoting awareness of their potential, and testing the appropriateness of the methodologies applied.

Material and methods

This work analyses the industry of wood based panels, particle and MDF boards, from 1990 to 2006. For this purpose, the data published by the European Panelboard Manufacturers Federation (EPF) are used because of its reliability about production, import and export figures. Moreover, the data was used concerning international trade published by Intrastat and handled by the Ministry of Industry (MITYC). The calculations are made in carbon mass units, using the conversion ratio from IPCC (IPCC, 2006; Lippke *et al.*, 2010).

Due to the differences of uses and developments of the two products studied, we should analyze them separately. Fig. 1 shows the distribution of uses for each type of panel, in the different decades evaluated to account for the carbon stock in the period 1990-2006 (Canals, 2010). The source of those data is the Spanish Wood Based Panels Manufacturers Association (ANFTA). It was considered that all the imported boards, fiber and particle ones present the same distribution of uses in percentage as the national ones.

Fig. 1a presents the different final uses for particleboards during the period of study in Spain. We can appreciate that until the 80s all the production went exclusively to furniture, till the moment it started to appear in construction with the percentage 20% to 25% in the period of 2000-2006. In the 90s a new usage was invented, technical flooring, which accounts for 10% of the production.

On the other hand, Fig. 1b compiles the particleboard distribution uses which are exported. During the 70s and 80s, they were only used in furniture, but since then they have been exported for construction.

Concerning the MDF, Fig. 1c shows the final uses throughout the study in Spain. Meanwhile in the 70s and the 80s the main utilization was in furniture, after they rapidly started to be used in construction and flooring, up to the levels of 25% and 18% respectively in the period 2000-2006.

Finally, Fig. 1d compiles the data of the exported MDF. The tremendous increase of this product for flooring is remarkable in the period 1990-1999 and 2000-2006, where it increased from 0% up to 70%.

Based on final usage, it was accepted a lifetime for the analyzed products. Lifetime is a necessary parameter to estimate the future emissions of HWP produced in the past (Skog and Nicholson, 1998). When wood products get to the end of their life, they can be recycled into a new product, increasing their lifetime,
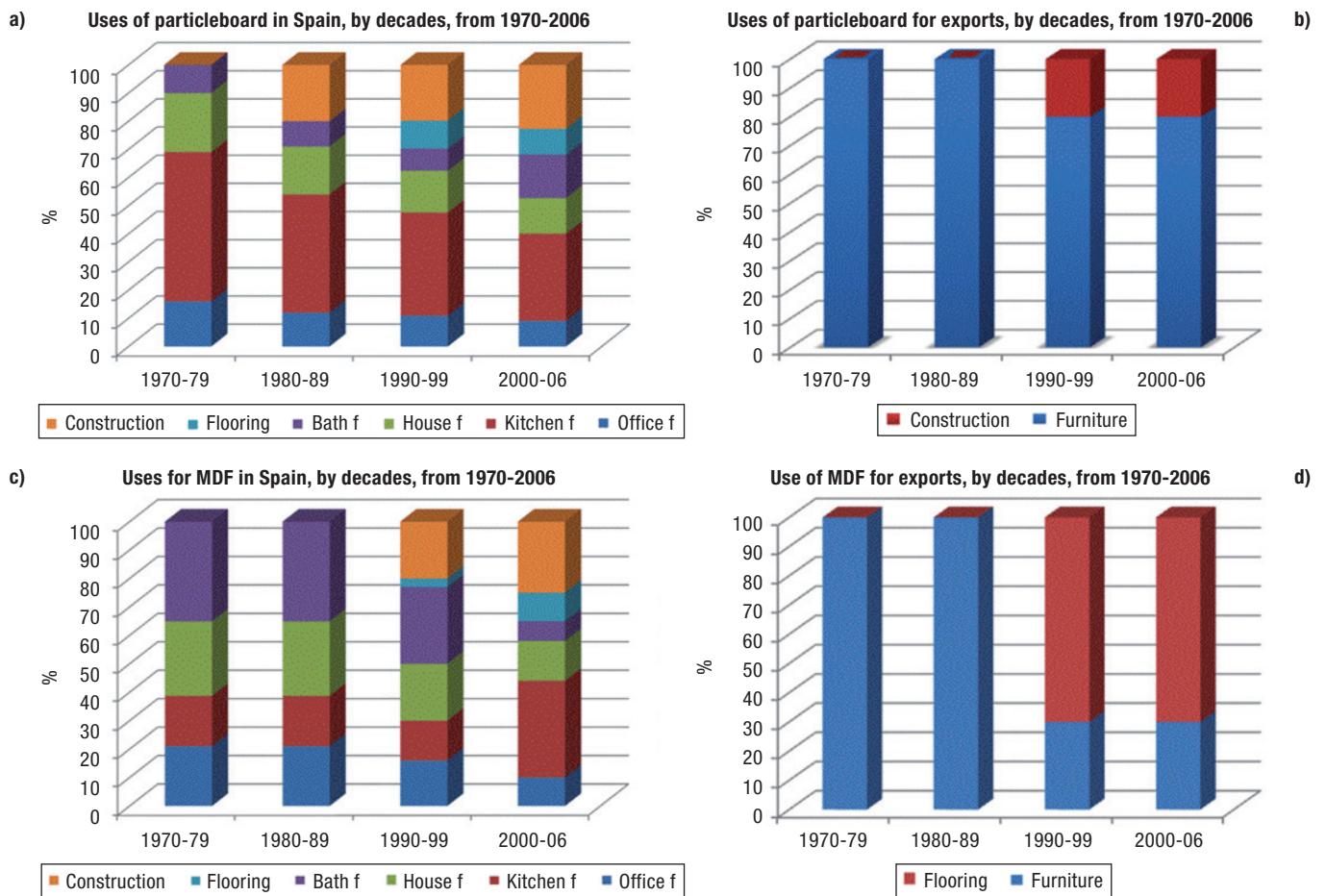
a) **Uses of particleboard in Spain, by decades, from 1970-2006**

b) **Uses of particleboard for exports, by decades, from 1970-2006**

c) **Uses for MDF in Spain, by decades, from 1970-2006**

d) **Use of MDF for exports, by decades, from 1970-2006**

Figure 1. Distribution of the different uses for particleboard and MDF in domestic consumption or export market by decades, from 1970-2006. *Source:* Spanish Wood Based Panels Manufacturers Association (ANFTA).

they can be burnt to produce energy, substituting fossil fuels, or they can be rapidly eliminated, or be left in solid waste disposal sites (SWDS), which implies a slow and long decay process (Pingoud *et al.*, 2003; Lippke *et al.*, 2010).

For this study, we have used the values provided by the French technological institute FCBA (Forêt, Cellulose, Bois-Construction, Ameublement) about the different lifetime of wood products, depending on their final use. Those values were adapted to the specific characteristics of the Spanish market. Furthermore, the decay process in SWDS was estimated as a lineal process, with a duration of 20 years.

Thus, Table 1 was elaborated according to our products.

The accounting of HWP in a compatible way with the national emissions inventories has been possible thanks to the methodologies developed by IPCC (IPCC, 1997a,b,c, 2003, 2006; UNFCCC, 2006). Spe-

cifically, this analysis was made using the 2006 IPCC Guidelines for National Greenhouse Gas (GHG) Inventories, Volumen 4 (AFOLU. Agriculture, Forestry and Other Land Uses), Chapter 12 (Harvested Wood Products), provided by the IPCC, and published in 2007.

So, this study is based on the three methodological approaches developed by IPCC experts in the meeting held in Dakar 1998. These approaches differ in the estimation of the net emissions and the boundaries of the system, but at a global level the three of them get the same result (Brown *et al.*, 1999; Vàcha, 2011).

The Stock Change Approach is focused on accounting for the annual changes in the carbon stock from the forest and HWP in a country, not taking into account the origin of the wood. In that sense, the imported HWP are accounted on but not the exported HWP. On the other hand the Production Approach assesses the changes in carbon stock according to the

Table 1. Average lifetime for the different final uses of panelboards in Spain (in years), based on FCBA & Ernest Young, 2008, modified by Canals G, 2010)

Final use	Average lifetime in use (years)	Average lifetime in SWDS (years)
Construction (roof, doors and moldings)	25	20
Flooring	15	
Furniture		
Office	10	
Houser	20	
Kitchen	18	
Bath	20	

national production of HWP and their export, meanwhile the imports of wood and HWP aren't considered. Finally, the Atmospheric Flow Approach evaluates the CO_2 flows in a country between the atmosphere, the forest and HWP. According to this approach, the HWP consumer countries don't increase their carbon stock through importing HWP, but they increase their emissions (Flugsrud *et al.*, 2001; Ford-Robertson, 2003; Skog, 2008).

The adoption of one approach or the other has different socio-economic and environmental implications, which are expressed in Table 2.

Table 2. Socio-economic and environmental implications by the different methodogical approaches

	Stock change approach		Production approach		Atmospheric flow approach	
	Annex I countries	**Non-annex I countries**	**Annex I countries**	**Non-annex I countries**	**Annex I countries**	**Non-annex I countries**
Trade implications	The net importers will import cheaper Wood. The net exporters will reduce their activity for products with a long lifetime.	The net importers will reduce their imports and increase their own production. The net exporters will increase both.	The net importers will increase their production. The net exporters will be interested in increasing their exports.	The net importers will be able to import more. The net exporters will be more incentivized to export.	They will reduce their imports and increase their exports.	If the international wood prices decrease, they will import more from the Annex I countries.
Bioenergy implications	Discourages the use of wood for energy uses in Annex I countries.		Discourages the use of wood for energy uses in Annex I countries.		Discourages the use of wood for energy uses in Annex I countries.	
Recycling implications	Provides incentives for recycling.		Provides incentives for recycling.		Increases the incentives for recycling.	
Environmental implications	Promotes the Sustainable Forest Management.	Increases the forest production.	Increases the forest production.	Reduces the production. Increases the imports for bioenergy.	Promotes the Sustainable Forest Management.	Could be a lower demand for their HWP.
Implications in limiting emissions	The Annex I countries can increase their domestic stock importing wood or HWP from non-Annex I countries.		There isn't a remarkable impact.		Negative consequences for the accounting of the emissions at the time of marketing.	

Source: Authors.

The Revised IPCC Guidelines (IPCC, 2006) proposed seven auxiliary variables to assess the carbon stock under the three different approaches mentioned above, with the aim of avoiding double counting with Waste and the Energy sector. Those variables, accounted in tonnes of carbon, are:

— 1A: Annual difference of HWP carbon stock in use for domestic consumption (production + imports – exports).

— 1B: Annual difference of HWP carbon stock in solid waste disposal sites from domestic consumption (production + imports – exports).

— 2A: Annual difference of HWP carbon stock in use in the country, produced by domestic wood.

— 2B: Annual difference of HWP carbon stock in solid waste disposal sites in the country produced by domestic wood from the country.

— PIM: carbon stock from the annual imports of wood for a country (wood products, semi-finished wood products and roundwood).

— PEX: carbon stock from the annual exports of wood in the country (wood products, semi-finished wood products and roundwood).

— H: carbon in annual harvest of roundwood for products, wood removed from harvest sites in the reporting country, including fuelwood.

Once the seven variables are calculated, it is possible, in general terms, to evaluate the HWP carbon stock with the three approaches (FCBA *et al.*, 2008). According to international criteria, in national GHG inventories emissions are in positive values and removals in negative values. However, this study has focused on the accounting of the CO_2 removals in HWP, the values are expressed in absolute values, with a positive sign

— Stock Change Approach: $\Delta CO_2 = 44/12 \times (1A + 1B)$.

— Production Approach: $\Delta CO_2 = 44/12 \times (2A + 2B)$.

— Atmospheric Flow Approach: $\Delta CO_2 = 44/12 \times [H - (1A + 1B)]$.

Moreover, depending on the level of detail, the calculation of the three different approaches can be done as level or tier 1, 2 or 3, increasing respectively on the accuracy and the country-specific data and methods. According to IPCC Guidelines 2006, and considering the existence of robust and reliable data on the Spanish Panelboard industry, particle and fibreboards, the present study is developed under level 3.

In IPCC Guidelines 2006, volume 4, chapter 12, different specific methods have been considered to measure the HWP carbon stock. Based on the lifetime values collected in Table 1, and the percentage distribution of final uses, the variables 1A and 2A were calculated using the demographic method, appropriate for long life products, as the panels are, mainly used in the furniture and construction sector. This method consists of rebuilding the stock accumulation process, describing the input and output fluxes.

The stock change is calculated comparing the values from two consecutive years, subtracting the present year from the previous one.

Demographic method

$$\Delta S_n = \left[\sum_{i=n-du}^{n} F_i - SO_n \right] - \left[\sum_{i=n-(du+1)}^{n-1} F_i - SO_{n-1} \right]$$

where: ΔS_n: stock variation in the year n, du: duration of stock, F_i: flux in the year i (stock input), SO_n: output stock in year n.

For calculating the variable 2A the import and export statistics were used, from panelboards and also from the wood needed to manufacture them. Meanwhile, to evaluate the variables 1B and 2B, the national statistics published by INE weren't used, due to the fact that it isn't possible to identify separately wood residues, for that reason the information provided by the industry was used. The variable 1B is calculated with the stock of products which were manufactured with national and imported wood. On the contrary, variable 2B is estimated only with the HWP produced with national wood.

It is accepted that 60% of products decay in anaerobic conditions (IPCC, 1997), meanwhile the remaining 40% decay completely and immediately (Skog *et al.*, 2004), assuming, that quantity cannot be accounted in the HWP carbon stock. Moreover some studies (Micales and Skog, 1997) indicate that panels can decay under anaerobic conditions during a period of time between 20 and 40 years, in this work it was decided, according to IPCC, to use the lower duration (IPCC, 2000).

Finally, a statistic analysis was developed, due to the uncertainties that the input data can cause. Due to the complexity derived from the amount of input variables and the recurrence of the formulas, the Montecarlo method was chosen to compare the results.

The Montecarlo methods are computational algorithms which draw on random repeated sampling to calculate the result from an equation. In this study, 5,000 iterations were made using the MATLAB® software.

Table 3. Statistic of the characterization of each of the parameters under tier 3

Variable	Source	PDF	Confidence interval 95%	Standard deviation (%)
K to covert t C for PB		K1 * K2 * K3		
K1: carbon content for wood dry tonne.	IPCC 2006	Normal	± 10%	± 5.1
K2: dry wood content in particleboards	Industry	Normal	± 5%	± 2.6
K3: density	Industry	Normal	± 8%	± 4.1
K to convert t C to for MDF		K1 * K2 * K3		
K1: carbon content for wood dry tonne.	IPCC 2006	Normal	± 10%	± 5.1
K2: dry wood content in MDF	Industry	Normal	± 5%	± 2.6
K3: density	Industry	Normal	± 8%	± 4.1
Percentages of uses for office, house, kitchen, bath and exports	Industry	Normal	± 6%	± 3.1
Lifetime	Industry	Normal	± 8%	± 4.1
Production (i year)	Industry	Normal	± 8%	± 4.1
Imports (i year)	Industry	Normal	± 8%	± 4.1
Exports (i year)	Industry	Normal	± 8%	± 4.1

This statistical analysis was made for the following objectives:

— To obtain the dispersion of the different variables (1A, 2A, 1B, 2B, Pim, Pex y H), in order to determine the uncertainty of the analysis, by way of understanding the standard deviation as a special tool to measure the uncertainty.

— To analyze the sensibility of the results in respect to the values of the input variables.

As in other previous studies like Skog *et al.* (2003) or Dias *et al.* (2007), in this study each input parameter was defined as a random variable with an associated probability density function (PDF). In this sense it is possible to determine the total uncertainty of the carbon stock in HWP evaluated.

Following the IPCC Guidelines 2006, a confidence interval of 95% was adopted.

In Table 3 we have presented the characterization of each of the parameters that have been considered as random variables in the method used for the calculation for stock variables.

Results

With the aim of verifying the correct programming to the calculations done in the Monte Carlo simulation, we compared the average values obtained by simulation with these same values applying the method in an analytical way without considering the input variables as random ones (Table 3). The coincidence of both results indicates a correct application.

Then, the average annual values of the seven auxiliary variables are presented:

— Variable 1A:

It has maintained an increasing tendency since 1960. We can underline that in 1989 it reaches a peak of over 500,000 t of carbon, with a dramatic drop in 1994. During the period 2000-2006 it suffers a notable increase till it reaches values of around 800,000 t of carbon.

— Variable 1B:

It shows two relative maxima in 1995 and 1999 with values around 108,000 and 130,000 t of carbon respectively. In the year 2000 a decrease is registered with values of 72,000 t of carbon, later to continue with an increasing tendency up to 163,800 t of carbon.

— Variable 2A:

As is logical, it registers lower values than variable 1A, because it doesn't account for the import fluxes. From 1990 there was a notable increase, reaching its absolute maximum value in 2006 with 916,000 t of carbon.

— Variable 2B:

In the years 1996-1998 a peak value is registered of 150,000 t, dropping in 2002 to 112,000 t. From 2004 the value increases to 180,000 t of carbon.

— Variable PIM:

This variable is only analyzed during the period 1990-2006, because there aren't accurate data available for the previous years. It presents two relevant peaks in 1992 and 1998 with 300,000 and 423,000 t respectively.

— Variable PEX:

It registers a saw tooth trend, with a steep slope of growth, primarily from 1996. In general terms, it ex-

Table 4. Results of the three methodical approaches in tier 3

	Stock change approach		Atmospherics flows approach		Production approach	
	Gg C	Cg CO$_2$	Gg C	Cg CO$_2$	Gg C	Cg CO$_2$
1990	580.15	2,127.23	435.94	1,598.45	615.60	2,257.19
1991	548.77	2,012.14	348.90	1,279.31	520.93	1,910.07
1992	527.86	1,935.49	325.34	1,192.91	502.64	1,843.02
1993	428.67	1,571.80	361.81	1,326.63	498.66	1,828.43
1994	492.20	1,804.73	456.95	1,675.49	503.44	1,845.94
1995	484.43	1,776.26	441.29	1,618.08	466.39	1,710.10
1996	492.13	1,804.49	445.60	1,633.88	476.46	1,747.02
1997	520.56	1,908.73	326.32	1,196.52	447.72	1,641.65
1998	543.82	1,993.99	269.56	988.39	439.36	1,610.99
1999	733.88	2,690.90	522.61	1,916.23	625.91	2,295.00
2000	855.79	3,137.90	685.21	2,512.45	854.11	3,131.73
2001	835.52	3,063.58	701.58	2,572.47	789.50	2,894.85
2002	797.99	2,925.96	818.37	3,000.70	905.42	3,319.88
2003	826.20	3,029.38	854.64	3,133.66	925.94	3,395.13
2004	836.48	3,067.10	947.35	3,473.61	1,014.80	3,720.95
2005	885.58	3,247.14	981.28	3,598.02	1,058.44	3,880.96
2006	960.70	3,522.56	1,019.81	3,739.31	1,096.85	4,021.79

plains the remarkable export capacity that this industry has developed in the last years of the study.

— Variable H:

This variable expresses the harvested wood that goes to the panel manufacture, particle and fiberboards. Its evolution is similar to the evolution of the production capacity of the analyzed industry, a clear increasing trend from 1998.

The numeric results of the three methodological approaches are presented in Table 4.

The upward trend of the three approaches is remarkable during the period of the study. With respect to the stock change approach, it presents higher values until the year 2002, when it is surpassed by the other two approaches. In relation to the production approach, it is the one which stores more carbon in the panels studied, reaching a maximum value close to 1.1 million t of carbon. Finally, the atmospheric flux approach presents relevant values of carbon store, surpassing a million tonnes of carbon in 2006.

The same results are presented in a graphic manner in Fig. 2. The different values that registered each approach are linked to the increasing importance of the export capacity of the panel industry.

To sum up this part, the values from the average dispersion for the seven auxiliary variables and the results obtained by the three approaches are presented in Table 5, which shows that the production approach is the one which registers a lower dispersion, followed

by the stock change approach. Meanwhile, the atmospheric flow approach is the one which registers higher uncertainty in its calculations that badly influence its results.

Discussion

To carry out this work we have consulted various studies for different countries, applying methodologies based on the IPCC Guidelines, except in the case of the United States and Switzerland, which follow a different methodological approach. In this study a specific method in line with Tier 3 methods proposed by
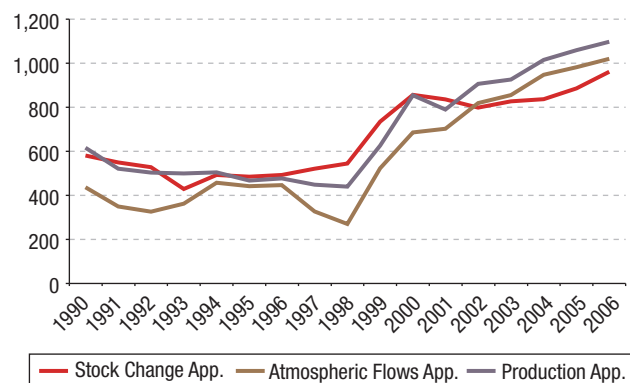

Figure 2. Results of the three methodological in tier 3 from 1990 to 2006 in tonnes of carbon (t C).

Table 5. Average dispersion with a confidence level of 95%, expressed as percent

Variable 1A	Variable 1B	Variable 2A	Variable 2B	Variable PIM	Variable PEX	Variable H
10.7	28	13.8	22.6	9.3	12.7	29.3
Stock change approach			**Production approach**		**Atmospheric flows approach**	
14.3			13.6		15.9	

Source: Authors.

the IPCC. This methodology allows great credibility in the calculations, due to the existence of accurate and reliable country-specific data. Although it doesn't make sense to compare quantitatively the results of all the studies consulted, as discussed different products, areas or time periods; however, they are very interesting to contextualize this work and review cardinal aspects of their preparation.

With respect to the lifetime of wood products in use, each study addresses the issue in a different way. Thus France, Germany and Portugal employ values that are based on experience, scientific literature or valuation of the industry itself. In accordance with this approach, this work has taken FCBA data, French technological institute, adjusting them to the peculiarities of the Spanish market. Regarding HWP out of service, according to different authors (Pingoud & Wagner, 2006; Dias *et al.*, 2009), and as indicated by the IPCC Guidelines, has opted for a first order decay in which 60% of the product decomposes under anaerobic conditions, while the remaining 40% is broken down completely and immediately (IPCCb, 1997; Skog *et al.*, 2004).

The first consideration of the results obtained highlights the spectacular increase in the stock of carbon stored in the particle and fiberboards. This fact can be explained by the increase in the productive capacity of the sector in Spain during the period. However, other studies (Flugsrud *et al.*, 2001; Pingoud *et al.*, 2003; Day *et al.*, 2005; Skog, 2008) indicate that carbon stocks in wood products have also increased in their respective countries during the last decades. It is clear, thus, the growing importance of wood products as carbon storages, and thus, their successful inclusion in national GHG inventories.

If we compare the results of different approaches, in this and in other studies, we found that the main difference between them lies mainly in the computation of exports and imports of wood products, ie which country are accounted and if they are quantified as carbon sequestration, or as emission. Thus, the impor-

tance of the production approach in this work since 1990, appears to be due to the growth of exports of panelboards during the period (1990-2002). It is also an industry with a high capacity of recycling wood, which it makes it a low dependence on the outside material. For this reason, another consequence of this work, according to several studies (Flugsrud *et al.*, 2001; FOEN, 2007; Sikkema *et al.*, 2013), is the importance of cascade use of wood, recycling wood products as often as possible, and going to landfill only those products that, after several cycles of reuse, have no other use and have to be disposed of or recovered energy.

As in previous studies (Skog *et al.*, 2004; Day *et al.*, 2006), this study performed a statistical analysis of the results. The statistics of the production and trade of wood products were the main sources of uncertainty in the estimates, regardless of the approach used. Furthermore, studies consulted also agree in highlight the rate of decomposition of wood products in use, the fraction of wood products going to landfills and the conversion factor of solid wood to dry volume.

Finally, the results obtained allow us to demonstrate the importance that forest management plays, in order to increase timber production, beneficial factor for all analyzed methodological approaches. Especially for the production approach, in which are accounted those products in use and decaying wood produced from domestic wood, and sold both at home and outside. It is therefore essential to properly coordinate climate change policy and forest policy, in order to promote not only the survival of the forests, but also the welfare of the rural population and labor involved in the production processes of the wood industry.

Conclusions

In this work the quantity of carbon stored in the Spanish particleboard and fiberboard has been evaluated, according to the available methodology from Revised

Guidelines IPCC 2006. First of all, it is important to clarify that apart from the methodological approach chosen for the HWP accounting, HWP plays a significant role in the national carbon inventory and is relevant in economic terms, because of Spain's compromise to reduce its emissions, it has to buy allowances from third countries.

The calculations have been developed according to level 3, because of the good quality data provided by the industry. However we would recommend the improving of the quality of the data related to imports.

The first consequence to underline in this analysis is the extraordinary increase of the carbon stock in panels (particle and fiber ones) in use and in decay during the period 1990-2006, for the three approaches mentioned. This circumstance is only achievable due to the important increase of capacity of production for this industry in the period of the study.

Comparing the results obtained by the different approaches, we can appreciate that the lower dispersion is presented by the production approach, followed by the stock change and finally by the atmospheric flow ones. This is due to the important deviation in average values for imports and exports in the last approach.

Meanwhile, if we compare the numeric results during the period 1990-2002, the stock change approach is the one which registered a higher carbon stock. However, up to that year, the production approach is the one which presents higher values of carbon stock, surpassing in 2004 a million carbon tones annually.

That leadership is explained by the increase of the exports of these products during the period of study. Moreover, it is a sector with a notable capacity to recycle wood, which allows it to lessen its dependence on foreign raw materials. For that reason, in the last decades the quantity of use of recycled wood has increased significantly in the manufacturing process and the need of imported wood has decreased.

Moreover, the reintroduction into the wood process of wood residues and wastes, and their consequent conversion into new long lifetime products, means that the carbon is kept for longer periods and it isn't released into the atmosphere (Flugsrud *et al.*, 2001; FOEN, 2007; Sikkema *et al.*, 2013). The efficient use of wood resources is at the core of the increasingly used concept of cascading use thereof.

Mantau (2012) defines cascade use as multiple use of the wood resources from trees by using residues, recycling (utilization in production) resources on re-

covered (collected after consumption) resources. Taking into account that cascade use does not take place in one single sector, but in several sectors, and as has indicated, the Spanish panelboard industry plays a backbone role in all the HWP productive chain, this concept is specially relevant not only for this work, but also for the study of the whole Spanish wood industry.

Also, when the wood reaches the end of its reuse, it will be even more important for energy purposes, thereby replacing a greater or lesser amount of fossil fuels, and improving the compliance with European regulations on waste.

In the light of these results, we can see the importance of forest management, as a way of increasing wood production, and increasing carbon storage. As was shown in this study, that was a favorable element for the three methodological approaches. Especially the production approach, in which all products are accounted in use or decay manufactured by domestic wood that is traded in the country and abroad. Summing up, perhaps the main conclusion of this study is the need for adequate coordination of the climate change and forest policies, in order to achieve successful results to ensure the survival not only of the forest, but also of the rural population and the work force involved in the productive process of the industry.

This work creates new lines for future scientific research. In this sense, it is important to update the calculations made, which will allow us to integrate the hard consequences that the economic crisis has brought, and still nowadays brings, to the sector. Furthermore, it would be very interesting to develop a similar level 3 analysis in different sectors of the wood industry, especially in the saw-mill industry. We mustn't forget that this industry has a great capacity for carbon storage due to the potential long lifetime of its products as structural elements in construction. The main objection developing this analysis could be the lack of reliable data to elaborate a study of that quality.

Finally, it is necessary to highlight the relevance of this study and its conclusions, as it is being discussed at European level Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Accounting for land use, land use change and forestry (LULUCF) in the Union's climate change commitments' (COM (2012)94 final), that states:

"In addition to the opportunities directly linked to forestry and agriculture, there are potential mitigation

benefits in related industries (*e.g.* pulp and paper, wood processing) (...) whilst carbon is stored in trees and in other plants and soils, it can also be stored for several decades in products, *e.g.* construction wood. Industry and consumer oriented policies can make a significant contribution to increasing the long term use and recycling of wood and/or production of pulp, paper and wood products as substitutes for more emission-intensive equivalents (*e.g.* concrete, steel, fossil-based plastic)".

Or, 'the Opinion of the European Economic and Social Committee on the 'Proposal for a Decision of the European Parliament and of the Council on accounting rules and action plans on greenhouse gas emissions and removals resulting from activities related to land use, land use change and forestry' (OJ, 2012), whereby:

"The EESC welcomes the EU proposal to include harvested wood products (HWP) in the accounting rules. Taking into account the carbon stock in these products enhances the role of wood and wood products in the evaluation and assessment of climate impact".

Acknowledgments

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