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Environmental assessment of wood-based panels: a comparison of life-cycle-based tools

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This paper aims at comparing three tools to assess the environmental impacts of building products: i) the ISO 14040/44 life cycle assessment methodology; ii) the environmental product declaration (EPD); and iii) PAS 2050. The particleboard was selected to illustrate this comparison. Four methodological differences between the tools were analyzed: biogenic CO_2 emission accounting, inclusion of capital goods, allocation procedure and cut-off criteria. Results show that the total environmental impacts for each impact category are different for each tool. In global warming, differences are very significant (above 100%), since PAS 2050 accounts for biogenic CO_2 and includes carbon storage, which reduces the impact in global warming, in opposition to ISO 14040/44 and the EPD. In other impact categories, differences vary between 3 and 25%, and are mostly related to the inclusion/exclusion of capital goods. The different allocation procedures and cut-off criteria used result in minor differences.

Keywords: Environmental product declaration, life cycle assessment, particleboard, PAS 2050

Introduction

The building and construction sector is increasingly demanding information on the environmental performance of buildings and building products. There are various environmental life-cycle-based tools that can be used to assess and communicate the environmental impacts of building products and materials, such as: the ISO 14040 series (for life cycle assessment methodology); environmental product declarations (EPD); and carbon footprint methods. Nevertheless, these tools adopt different methodological approaches. To understand the differences between these tools as well as how they can influence the results is of key importance for decision makers. This paper intends to support companies, particularly from the wood and furniture sectors, in implementing environmental life-cycle-based tools for assessment, management and communication purposes. Additionally, it aims at contributing to the improvement of these tools among the technical and scientific community.

Life cycle assessment (LCA) is a methodology that allows a systematic assessment and quantification of the potential environmental impacts associated with a product life cycle (ISO 2006a,b; Guinèe, 2002). It has been applied to a number of building product systems, including wood-based panels (e.g. Rivela et al., 2006, 2007; González-García et al., 2009; Wilson, 2010a; Garcia &Freire, 2011). The generic LCA methodology has been standardized by the International Organization for Standardization, resulting in the ISO 14040 series standards. These standards are the basis for the development of several life-cycle-based tools, such as environmental product declarations and carbon footprint methods.

Environmental product declarations (EPD) are business-to-business and business-to-consumer communication tools that provide quantified life-cycle environmental data for a product, namely environmental impacts, resource consumption and additional environmental information (ISO, 2006c). The

ISO 14025 (ISO, 2006c) standard provides the principles and requirements for developing EPD for products in general, while the ISO 21930 (ISO, 2007) standard is specific for building products. An EPD is based on a LCA study developed according to product category rules (PCR) established for products with similar functions, in order to enable comparisons. The PCR identify and define the requirements that need to be fulfilled in the development of an EPD of a particular product category, such as the goal and scope of the data, the life-cycle phases to be included, the impact categories to be analyzed and the presentation of results. These PCR are developed according to LCA studies based on the ISO 14040 series standards. There are several EPD programs and different PCR for building products. Nevertheless, in recent years, there has been an effort to harmonize the PCR from different EPD programs (Ingwersen& Stevenson, 2012). The most recent PCRfor wood-based panels is from the International EPD System (Environdec, 2012).

Other life-cycle-based tools frequently used are carbon footprint methods. The carbon footprint of a product is usually defined as the quantification of the life-cycle greenhouse gas (GHG) emissions of a product. There are several carbon footprint methods both available and in development. The British Standards Institution (BSI) has recently published a revised version of the Publicly Available Specifications (PAS) 2050 regarding the assessment of the life-cycle GHG emissions of goods and services (BSI, 2011). The ISO is preparing a standard on the requirements and guidelines for the quantification and communication of the carbon footprint of products (ISO/DIS, 2012). The Greenhouse Gas Protocol Initiative, from the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD), developed a standard to quantify and report the life-cycle GHG emissions of a product (WRI/WBCSD, 2011). All these approaches are based on the ISO 14040 series standards, but introduce specifications in the GHG emission calculation method.

This paper aims at comparing three different tools to assess and communicate the environmental impacts of building products: i) the ISO 14040 series LCA methodology (ISO 14040/44); ii) the environmental product declaration (EPD); and iii) PAS 2050. This comparison has been performed based on an application to particleboard, which represents about 43% of the Portuguese wood-based panel production and is an important product in the context of the building and furniture sectors (AIMMP, 2010). A particleboard is a wood-based panel made from wood particles, mainly wood residues from different sources, usually aggregated using urea-formaldehyde resin. For EPD, the most recent PCR for wood-based panels from the International EPD System were used (Environdec, 2012). A comparative assessment of the methodological differences of the three tools and a critical assessment of the results obtained by their application to the particleboard case-study are the main outcomes of this paper.

Life-cycle-based tools applied to particleboard

Life-cycle model

Figure 1 shows the life-cycle model flowchart. Both cradle-to-gate (from raw material extraction/cultivation to panel production) and cradle-to-grave (whole life cycle) models have been developed. The cradle-to-gate model includes the forest operations of site preparation, planting and logging (harvesting and forwarding) of wood, the sawmill process, the production of urea-formaldehyde resin (UF resin) used to bind the wood particles and the particleboard production. The wood used to produce particleboard comes from four different sources: sawmill sub-products (30%), post-consumer wood (30%), pine forest residues (25%) and eucalyptus forest residues (15%) (Garrido et al., 2010). In addition, the model takes into account the production of fuels, electricity and other chemicals as well as transport of raw and ancillary materials. The cradle-to-grave model also includes transport of particleboard to the distribution platform and the end-of-life, for which three scenarios are considered: i) landfill disposal (100%); 2) incineration 100%); and 3) recycling (30%) and incineration (70%). The particleboard life-cycle model builds on research previously presented in Garcia (2010) and Garcia & Freire (2011).

The functional unit is 1 m^3 of uncoated particleboard for non-structural use (density of 640 kg/m^3), which is consistent with EPD. The ISO 14040/44 standards and PAS 2050 do not establish a functional unit for specific products. Nevertheless, similar guidance for the definition of the functional unit is given by all the methodologies under analysis.

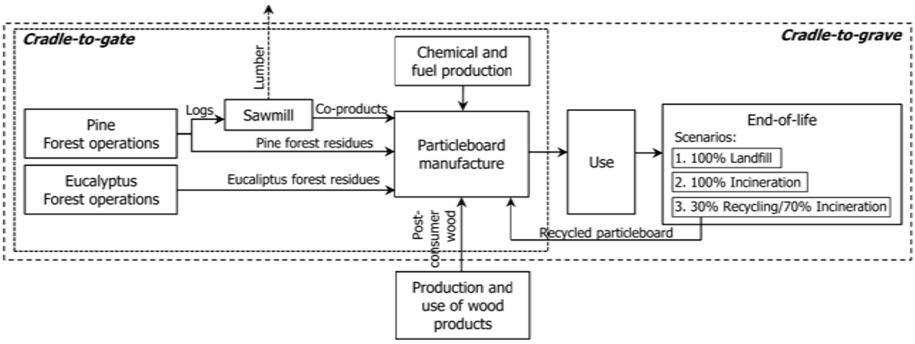

Figure 1. Particleboard life-cycle model flowchart.

The main sources of data are peer-reviewed literature and databases. Whenever possible, specific data for the Portuguese context was gathered. Fuel consumption (diesel and gasoline) in eucalypt and pine forest activities have been estimated based on Nunes (2008) and Dias et al. (2007), respectively. Data regarding the sawmill process was collected from Milota et al. (2006) and the production of UF resin process was modeled based on data from Wilson (2010b). The main data source for particleboard manufacturing process was Rivela et al. (2006). Average transport distances for Portugal of materials for the main production processes and distribution of the particleboards were considered. Electricity generation for the main processes was modeled using the Ecoinvent database, with reference to the 2010 Portuguese mix (REN, 2011). Data regarding other raw and ancillary material and fuel production is from the Ecoinvent database (Ecoinvent, 2012). Regarding particleboard end-of-life, both Ecoinvent data for sanitary landfill disposal and incineration of wood were considered (Doka, 2009). The latter was modified to include NOx emissions from particleboard, according to Risholm-Sundman&Vestin (2005), since other emissions were assumed similar to those from wood incineration.

The impact categories selected for the life cycle impact assessment (LCIA) are those referred in the PCR for the EPD, namely global warming (GWP100), ozone layer depletion, photochemical oxidation, acidification, and eutrophication (Environdec, 2012). ISO 14040/44 standards do not provide guidance on which specific categories to include in the study, but state that their choice shall be consistent with the goal and scope and shall provide a comprehensive set of environmental issues related to the product system. For the purpose of comparison of results, the previously selected impact categories are also analyzed using the ISO 14040/44 standards. Regarding PAS 2050, only global warming is assessed, since these standards apply only to product life-cycle GHG emissions.

Methodological differences

The main methodological differences between the three tools analyzed in this study (ISO 14040/44, EPD and PAS 2050) are presented in this section. These differences are related to the cut-off criteria used, the inclusion or exclusion of capital goods, the approach used to deal with multifunctional processes and biogenic CO_2. Table 1 summarizes the approaches used by each tool regarding these issues.

Table 1. Main methodological differences between the tools.

	ISO 14040/44	EPD	PAS 2050
Cut-off criteria	Not specified	<5% environmental impacts	<5% total GHG emissions
Capital goods	Included	Excluded	Excluded
Multifunctionality	Scenarios	Mass allocation	Economic allocation
Biogenic CO_2	Not specified	Excluded	Included
No. of impact categories	5	5	1

ISO 14040/44

The ISO 14040 series standards for LCA methodology is the basis for the development of the EPD and PAS 2050. Nevertheless, modeling choices and different approaches to some methodological issues exist, as discussed below.

Cut-off criteria are established to determine the input and output flows to be included in the assessment. Contrary to the other tools, the ISO 14040/44 standards do not define quantified thresholds but state that those should be based on mass, energy and environmental significance. In this study, no cut-off criteria were defined. Other difference between the tools concerns capital goods, which are explicitly included in the system boundaries in ISO 14040 (ISO, 2006a, Section 5.2.3), in opposition to the EPD and PAS 2050.

The approach used to deal with multifunctional processes is another important difference between the tools. In this study, the sawmill process is a multiple output process since it simultaneously produces planned lumber for the construction industry (main product) and sawdust, chips and shavings used in the production of particleboard. Since the focus of this study is on particleboard, it is necessary to allocate the burdens to the product under analysis. ISO 14044 establish a hierarchy of procedures to deal with multifunctional processes (ISO, 2006b). Whenever possible, allocation should be avoided by sub-dividing the unit process or by system boundary expansion. Where allocation cannot be avoided, the burdens should be partitioned based on physical relationships. Where these cannot be established, other criteria should be used, such as the economic value of the co-products. Whenever several alternative allocation procedures seem applicable, a sensitivity analysis shall be conducted. In this study, two allocation procedures were used: mass allocation (ma) and economic allocation (ea). The allocation factors calculated for each procedure are presented in Table 2.

Biogenic CO_2 emission accounting is particularly important in the assessment of wood-based products. During photosynthesis, there is an uptake of CO_2 by trees. This CO_2, known as biogenic CO_2, is eventually released back to the atmosphere and is thus considered neutral.Biogenic CO_2 accounting is, however, a controversial issue among the LCA community (Guinèe, 2009; Brandão and Levasseur, 2011).The ISO 14040/44 standards do not mention any specific approach regarding biogenic CO_2.In this article, biogenic CO_2 emissions were not accounted (i.e. Global Warming Potential for biogenic CO_2 is assumed 0). This complies with the approach used by the most recent IPCC GWP100 v1.02 impact assessment method (Solomon, 2007).

EPD

According to ISO 14025 (ISO, 2006c), an Environmental Product Declaration (EPD) is based on a LCA study developed according to product category rules (PCR) established for the category of the product under analysis. In this study, the PCR used is the most recent one for wood-based panels from the International EPD System (Environdec, 2012). Compared to PAS 2050, the environmental assessment of the EPD is more similar to the ISO 14040 standards, since several impact categories are analyzed. The main methodological differences of the EPD compared to the other tools are presented next.

The EPD states a minimum of 95% of total inflows to be considered in the assessment and allows the exclusion of processes that contribute to less than 1% of the total environmental impacts and/or that represent less than 1% of the mass input. Due to these cut-off criteria, the production of the ammonium sulfate used in the particleboard production was not taken into account. Moreover, according to the EDP, personnel activities, building of site, infrastructure and equipment, i.e. capital goods, werealso excluded from the system boundaries. The procedure defined in the EPD to deal with the allocation of burdens between co-products is the one based on mass and no other criteria is allowed. Thus, that was the procedure used in this study for allocating burdens in the sawmill process. Regarding biogenic CO_2, EPD excludes both the uptake of CO_2 and the emissions of biogenic CO_2 from the GWP calculations. As a result, carbon storage in wood products is not taken into account.

Table 2. Allocation factors for sawmill co-products.

Sub-process	Co-products	Mass allocation	Economic allocation[a]
Sawing	Rough green lumber	56%	85.7%
	Sawdust	7%	2.3%
	Chips	37%	12.0%
Planing	Planed dry lumber	85%	96.4%
	Shavings	15%	3.6%

[a]INE, 2010

PAS 2050

The assessment of the carbon footprint using PAS 2050 may be regarded as a reduction of the scope of an ISO 14040 LCA study, since only one environmental impact category is analyzed: global warming. PAS 2050 requires the inclusion of all the processes that contribute to more than 1% of the anticipated life-cycle emissions of the functional unit and at least 95% of the total GHG emissions associated with the product. As a result of these cut-off criteria, GHG emissions associated with the production of biomass, ammonium sulfate and paraffin used in particleboard production has been excluded from the system boundaries. Similarly to the EPD, the production of capital goods, transport of workers to and from the place of work and transport of costumers to and from the point of purchase have also not been taken into account.

Regarding multifunctionality, PAS 2050 uses a similar approach to the ISO 14040 standards. Firstly, allocation shall be avoided by sub-dividing the unit process or by system boundary expansion as in ISO 14040/44. Where neither of those approaches is practicable and there are supplementary requirements available, these should be used. Lastly, if none of these procedures is applicable, allocation shall be made according the economic value of the co-products. In this study, economic allocation was used.

Concerning emissions and removals of biogenic CO_2, PAS 2050 has a different approach compared to the other tools, since these are included in the assessment of the life-cycle GHG emissions of the product (global warming impact). Based on the fact that, during biomass growth, there is an uptake of CO_2 from the atmosphere which is temporarily stored in wood-based products and left out of the atmosphere for a certain period of time, which results in postponing its effect on global warming, PAS 2050 also proposes a method for the calculation of the weighted average impact of a delayed release of the stored carbon (BSI, 2011, Annex E, p.33). Nevertheless, that assessment is not mandatory and has to be done in parallel with the identification of the impact without the effect of timing of emissions (single release assessment). For the calculation of the weighting factor, a service life of 10 years for particleboard was considered.

Application of the tools: comparative assessment

Cradle-to-gate assessment

Table 3 shows the cradle-to-gate impact assessment results of the three tools. The life-cycle impact assessment method used was CML 2 v2.05 (Frischknechtet al., 2003). The upstream processes include production of biomass, UF resin, other chemicals and fuels, their transport to the industrial site and electricity generation. The core processes encompass the industrial process of particleboard production and on-site energy production. As can be seen in Table 3, the total environmental impacts calculated for each impact category are different for each tool. For all impact categories, mass allocation (ma) ISO 14040/44 presents the higher values, followed by economic allocation (ea) ISO 14040/44, EPD and, finally, PAS 2050, with the lowest results. The major differences occur when comparing PAS 2050 (negative value) and the other tools (positive values) in global warming and are mainly due to the inclusion of emissions and removals of biogenic CO_2 in PAS 2050. For the other impact categories, differences vary between 3%, when comparing mass allocation ISO 14040/44 and economic allocation ISO 14040/44 scenarios for ozone layer depletion, and 25% regarding eutrophication for mass allocation ISO 14040/44 versus EPD.

Capital goods account for 7 to 25% of the impacts and are the main responsible for the differences in results between ISO 14040/44 scenarios and EPD. Despite the exclusion of capital goods being a common practice in LCA studies (Frischknecht et al., 2007), results show that, for particleboard, they have a significant impact and should not be neglected. The allocation approach used can result in smaller differences, about 3 to 6%, since sawmill co-products represent less than 30% of the mass inputs to particleboard production. The different cut-off criteria account for differenced of 0.8% (EPD) and 3.5% (PAS 2050).

Concerning the processes that contribute the most to the environmental impacts (except global warming and photochemical oxidation), the results of all the tools are consistent and show that the upstream processes are the ones with higher impacts, representing between 69% (EPD, eutrophication) and 99% (EPD, ozone layer depletion) of the total impacts. UF resin production alone is responsible for 26 to 53% of the impacts. Nevertheless, the higher absolute differences in the results of the various tools come from the upstream processes. This is due to a combination of methodological differences that are related to the assessment of these processes, namely different cut-off criteria, different approaches regarding capital goods and different allocation procedures used. The differences in the core processes are caused only by differences in the inclusion of capital goods, and, for that reason, are much smaller. For global warming and photochemical oxidation, the relative importance of upstream and core processes is different depending on the tool.

Table 3. Cradle-to-gate impact assessment results per m^3 of particleboard.

Impact categories	Tools	Total	Upstream processes	Core processes
Acidification ($kg\ SO_2eq$)	ISO 14040/44 (ma)	0,68	0,49	0,18
	ISO 14040/44 (ea)	0,64	0,46	0,18
	EPD	0,59	0,42	0,17
	PAS 2050	-	-	-
Eutrofication ($kg\ PO_4^{3-}eq$)	ISO 14040/44 (ma)	0,21	0,16	0,06
	ISO 14040/44 (ea)	0,20	0,15	0,06
	EPD	0,16	0,11	0,05
	PAS 2050	-	-	-
Global warming ($kgCO_2eq$)	ISO 14040/44 (ma)	187	122	65
	ISO 14040/44 (ea)	182	116	65
	EPD	172	109	63
	PAS 2050	-936	-1313	377
Ozone layer depletion (g CFC-11 eq)	ISO 14040/44 (ma)	0,0195	0,0192	0,0004
	ISO 14040/44 (ea)	0,0190	0,0186	0,0004
	EPD	0,0181	0,0179	0,0002
	PAS 2050	-	-	-
Photochemical oxidation ($kg\ C_2H_4eq$)	ISO 14040/44 (ma)	0,048	0,025	0,023
	ISO 14040/44 (ea)	0,045	0,022	0,023
	EPD	0,043	0,021	0,022
	PAS 2050	-	-	-

ma: mass allocation; ea: economic allocation

Cradle-to-grave assessment

Table 4 shows the cradle-to-grave impact assessment results for the three tools and end-of-life scenarios. Analogously to the cradle-to-gate assessment, results are different for each tool in all impact categories and are higher for mass allocation ISO 14040/44 and lower for PAS 2050. The major differences appear in global warming, when comparing PAS 2050 and other tool results for recycling/incineration and landfill disposal scenarios. If carbon storage is taken into account, as in PAS 2050, both recycling/incineration and landfill scenarios show a great benefit in this category, resulting in less 335 and 1125 kg CO_2eq/m^3 of particleboard, respectively, compared to mass allocation ISO 14040/44 results. Since this benefit is not taken into account by the other tools, the comparison with other products which do not store carbon can be compromised. Regarding incineration, accounting for the fact that delayed GHG emissions have less impact in global warming, as in PAS 2050, can result in less 53% impacts in global warming compared to mass allocation ISO 14040/44.

For the other impact categories, differences in results can reach 18%, when comparing mass allocation ISO 14040/44 and EPD recycling/incineration scenario in eutrophication, and are mainly due to the inclusion or exclusion of capital goods. The end-of-life scenario with higher environmental impacts in acidification is incineration, regardless of the tool used for the assessment. For eutrophication and photochemical oxidation, landfill disposal is the scenario that presents higher contributions in all the tools. Regarding global warming and ozone layer depletion, different tools provide different rankings for end-of-life scenarios.

Table 4. Cradle-to-grave impact assessment results per m^3 of particleboard.

Impact categories	Tools	End-of-life scenarios		
		100% Landfill	100% Incineration	30% Recycling + 100% Incineration
Acidification ($kg\ SO_2eq$)	ISO 14040/44 (ma)	0,89	1,06	0,91
	ISO 14040/44 (ea)	0,85	1,03	0,88
	EPD	0,75	0,94	0,87
	PAS 2050	-	-	-
Eutrophication ($kg\ PO_4^{3-}eq$)	ISO 14040/44 (ma)	1,93	0,47	0,40
	ISO 14040/44 (ea)	1,92	0,46	0,39
	EPD	1,87	0,40	0,33
	PAS 2050	-	-	-
Global warming ($kg\ CO_2eq$)	ISO 14040/44 (ma)	433	230	228
	ISO 14040/44 (ea)	426	223	222
	EPD	287	201	204
	PAS 2050	-692[a]	193[a]	-107[a]
		-645[b]	108[b]	-170[b]
Ozone layer depletion (g CFC-11 eq)	ISO 14040/44 (ma)	0,026	0,026	0,026
	ISO 14040/44 (ea)	0,026	0,025	0,025
	EPD	0,022	0,023	0,023
	PAS 2050	-	-	-
Photochemical oxidation ($kg\ C_2H_4\ eq$)	ISO 14040/44 (ma)	0,078	0,060	0,058
	ISO 14040/44 (ea)	0,078	0,057	0,055
	EPD	0,073	0,052	0,051
	PAS 2050	-	-	-

ma: mass allocation; ea: economic allocation

[a] Single release assessment

[b] Includes the effect of delayed emissions

Conclusions

There are several environmental life-cycle-based tools to assess and communicate the environmental impacts of building products. These tools adopt different methodological approaches.The main purpose of this article is to compare the outcomes and implications of using the following three well-known tools: i) the ISO 14040 series LCA methodology (ISO 14040/44); ii) the environmental product declaration (EPD); and iii) PAS 2050. This comparison has been performed based on an application to particleboard. Both cradle-to-gate and cradle-to-grave assessments were performed, and three scenarios for particleboard end-of-life were considered, namely 100% landfill disposal, 100% incineration, and 30% recycling/70% incineration.

Results show that the total environmental impacts for each impact category are different for each tool, both in cradle-to-gate and cradle-to-grave assessments. These differences can surpass 100%, in global warming. Four methodological differences between the three tools were found to have an influence in the results: biogenic CO_2 accounting, the inclusion/exclusion of capital goods, the approach used to deal with multifunctional processes and the cut-off criteria used.

The treatment of biogenic CO_2 is responsible for the main differences in global warming. Compared to the other tools, PAS 2050 results for recycling/incineration and landfill disposal scenarios show a great benefit in global warming (up to less 335 and 1125 kg CO_2eq/m^3 of particleboard, respectively) due to carbon storage. Since this benefit is not taken into account by the other tools, the comparison with other products that do not store carbon can be compromised. For incineration, PAS 2050 results show up to less than 53% of impacts in global warming, when the assessment of delayed emissions of biogenic CO_2 was included. These outcomes show the importance of the treatment of biogenic CO_2 emissions in the global warming results of wood-based products. Thus, this issue should be further analyzed in future research.

The inclusion/exclusion of capital goods is the main responsible for the differences in results in the cradle-to-gate assessment, and accounts for 7 to 25% of the impacts in the cradle-to-gate assessment. Exclusion of capital goods is a common practice in LCA studies (Frischknecht et al., 2007) and is the approach followed by both EPD and PAS 2050. Nevertheless, results show that, for particleboard, they have a significant impact and should not be neglected. The allocation procedure used (mass, in EPD; economic, in PAS 2050; both scenarios, in ISO 14040/44) can result in smaller differences, about 3 to 6%, since sawmill co-products represent less than 30% of the mass input to particleboard production. The different cut-off criteria represent minor differences, since only processes which account for less than 0.8%, in EPD, and 3.5%, in PAS 2050, of total impacts were excluded.

EPD allows for a comprehensive assessment of the environmental impacts since several impact categories are analyzed. However, EPD implementation is based on Product Category Rules (Environdec, 2011) that do not account for the benefit of carbon storage and exclude capital goods, which were found to be important. PAS 2050 also exclude capital goods from the assessment of the life-cycle GHG emissions. Nevertheless, both emissions and removals of biogenic CO_2 are included in the assessment and a method for the assessment of delayed emissions is suggested, which are important methodological aspects especially for wood-based products. PAS 2050 has the potential to introduce and promote the implementation of life-cycle approaches at company level. On the other hand, it only considers one environmental aspect, which may compromise the assessment of potential tradeoffs. This is particularly important in wood-based products, since the benefit of carbon storage can mask worst performances in other categories.

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