Impacts of the Allocation Assumption in Life-Cycle Assessments of Wood-Based Panels*

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Abstract

Wood processing often involves an array of products and coproducts and a cascade of primary and secondary uses. Prior life-cycle assessment (LCA) reporting allocated environmental burdens to products and coproducts based on mass for multiproduct systems to develop environmental product declarations, which are developed from LCAs following the procedures detailed in product category rules (PCRs). A recent PCR for North American structural and architectural wood products requires allocation by economic value when the main products exceed the value of coproducts by greater than 10 percent. Using recent LCAs of wood-based panels, this article describes the differences in LCA results when using mass and economic allocation methods. For wood panel products that do not use wood residues from primary wood manufacturers (e.g., plywood), an increase in environmental impacts results from an economic allocation approach. For wood panel products made from wood residues (e.g., cellulosic fiberboard), there is a slight decrease in most environmental impact metrics with economic allocation. Sensitivity and variability in LCA results are discussed for the mass and economic allocation approaches.

Wood processing often involves an array of products and coproducts. Life-cycle assessment (LCA) of wood products therefore must divide—or *allocate*—the environmental impacts of the whole process to these various products and coproducts. Allocation can be done according to the relative mass, volume, or economic value of the products and coproducts, but the results of the LCA will vary with the type of allocation chosen (International Organization for Standardization [ISO] 2006a, 2006b).

A product category rule (PCR) is a set of instructions derived from ISO Standard 14025, ''Environmental Labels and Declarations—Principles and Procedure'' (ISO 2006c), which is used to prepare LCAs for products that are similar in some way (i.e., in the same category). A PCR is often intended to enable the preparation of an environmental product declaration, a standardized summary of environmental impacts for a particular product (ISO 2006c). To help ensure consistent evaluation of products within a category, a PCR can provide guidance on system boundary determination, reference units, and on allocation method. In 2015, a new North American PCR was published for wood product LCAs that requires allocation by economic value (FPInnovations 2015). The original PCR by FPInnovations was based on two previous (expired) European wood

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Table 1.—Price conversions for economic allocation, 2012.[a]

	Nominal value		Density (kg/m^3)		Volume	Specific value ($/kg)		
Product	Price ($)	Unit	PNW	SE	(board ft/m^3)	PNW	SE	Data source
Logs (west)[b]	494	MBF (scaled log volume)	450	470	139	0.15	—	Random Lengths (2012, p. 9)
Logs (south)[c]	44	Green ton[d]	450	470		—	0.05	Random Lengths (2012, p. 9)
Lumber, rough green[e]	322	MBF	450	470	530	0.38	0.36	Random Lengths (2012, p. 4)
Chips, green[f]	94	Dry ton				0.10	0.10	Random Lengths (2012, p. 9)
Chips, dry	94	Dry ton				0.10	0.10	Same as green chips per dry ton
Residues	20	Dry ton				0.02	0.02	M. Milota (personal communication, 2005)
Green veneer	34	MSF	446	503		0.09	0.08	Random Lengths (2012, p. 8)
Dry veneer	46	MSF	446	503		0.12	0.10	Random Lengths (2012, p. 8)
Plywood	250	MSF (3/8-in. basis)	446	503		0.69	0.56	Random Lengths (2012, p. 8)
Oriented strandboard	254	MSF		503			0.57	Random Lengths (2012, p. 8)

[a] PNW = Pacific Northwest; SE = Southeast; MBF = thousand board feet; MSF = thousand square feet.

[b] Average western species delivered sawlog costs.

[c] Average southern pine delivered sawlog cost.

[d] Short ton = 2,000 lb.

[e] Framing lumber composite price annual average.

[f] North American conifer chip prices.

product PCRs, and the current version was harmonized with other European standards (e.g., EN 15804 [2012] and EN 16485 [2014]). LCAs for wood-based panels have recently been updated (Puettmann et al. 2016a, 2016b, 2016c, 2016d, 2016e), but in previous reports, allocations were on a mass basis (Kline 2005; Wilson and Sakimoto 2005; American Wood Council–Canadian Wood Council 2013a, 2013b; Bergman 2015a, 2015b). To be consistent with previous reports and to comply with the new PCR, the recent updates have reported the LCA results separately for both mass and economic value allocation methods. This provides an opportunity to investigate the impact of the allocation decision on wood products LCA; this article describes the differences in LCA outcomes resulting from changes in the allocation method, using examples from softwood plywood, oriented strandboard (OSB), and cellulosic fiberboard.

Methods

The objective of this study was to use data from attributional LCAs of selected wood panels (softwood plywood, OSB, and cellulosic fiberboard) to illustrate the varying impacts of the mass or economic allocation on LCA results. The LCAs used were cradle-to-gate in scope and incorporated recent survey data from manufacturing operations, updated boiler process data, and preexisting forest management and harvest data. Softwood plywood and OSB were manufactured in the Southeast (SE) region of the United States, whereas cellulosic fiberboard production covered North America. Production data were collected from manufacturing facilities representing 2012 production values (Bergman 2015b, Kaestner 2015). For the mass allocation approach, the (ovendry) mass balance of wood inputs and outputs was developed based on survey data. For the economic allocation approach, the PCR allocation rule was applied for the main product and coproducts in the production system, which states that when the market price of the main product and coproducts differs by more than 10 percent, allocation shall be based on the relative market price (economic value). The 10 percent rule was applied based on a per unit basis, in this case, per cubic meter of each panel product. Product and coproduct market prices were estimated from a variety of sources (Table 1). These data were used to determine the relative allocation to the various products and coproducts for each panel type (Table 2).

These panel products represent a range of product and coproduct scenarios. Within the range of products studied here, structural softwood plywood is made from a relatively high-value raw material (high-quality, ‘‘veneer’’ logs), and a high-value coproduct (veneer) is a commercial product that is used in secondary wood products, such as laminated veneer lumber. OSB uses lower-value logs but is a high-value product, nearly equivalent in function to structural plywood, with very little coproduct during manufacturing. Cellulosic fiberboard is a relatively low-value panel made from low-value coproducts (i.e., residues) of (primarily) lumber production (a relatively high-value product).

Table 2.—Mass and economic allocation to products and coproducts for each panel type.

	Burden assigned to product or coproduct (%)	
Product and coproducts	Mass allocation	Economic allocation
Plywood	32.02	50.82
Bark	8.68	0.37
Green veneer that is sold	14.15	16.94
Green veneer clippings	8.49	13.95
Peeler core	13.19	3.99
Dry veneer that is sold	11.28	13.17
Plywood trimmings	3.05	0.21
Sawdust	0.55	0.05
Hog fuel	8.58	0.52
Oriented strandboard	75.15	97.50
Panel trim	0.30	0.03
Sawdust	1.33	0.14
Hog fuel	20.23	2.07
Wood waste	2.59	0.26
Ash	0.40	0.00
Cellulosic fiberboard	96.1	100
Culled boards	0.4	0
Wood molasses	2.2	0
Pins and fines	0.7	0
Other	0.6	0

Table 3.—Change in environmental impact indicators for various wood-based panels resulting from using economic allocation instead of mass allocation.

Impact category	Unit	Percent change from mass to economic allocation[a]		
		CFB	OSB	SE plywood
Global warming	kg CO_2 eq	−0.15	7.6	26
Acidification	SO_2 eq	0.02	7.0	25
Eutrophication	kg N eq	−11.00	4.7	16
Ozone depletion	kg CFC-11 eq	0.00	7.9	24
Smog	kg O_3 eq	−3.7	6.2	22
Primary energy consumption				
Total	MJ	−2.0	7.7	26
Nonrenewable fossil	MJ	−0.07	7.3	26
Nonrenewable nuclear	MJ	−0.61	7.9	28
Renewable (solar, wind, hydroelectric, and geothermal)	MJ	1.7	7.8	27
Renewable (biomass)	MJ	−11	8.0	27
Material resources consumption (nonfuel resources)				
Nonrenewable materials	kg	0.25	8.1	25
Renewable materials	kg	−3.0	8.0	0.55
Freshwater	liters	2.4	8.0	29
Waste generated				
Solid waste	kg	1.9	7.3	28

[a] CFB = cellulosic fiberboard; OSB = oriented strandboard; SE = Southeast; CFC = chlorofluorocarbon.

Results and Discussion

The choice between mass and economic value allocation between products and coproducts affects the results of life-cycle impact assessment (LCIA) (Table 3). In general, if a manufacturing process produces low-value coproducts, then applying economic allocations will shift the burdens to the main product, as seen in plywood. When little coproduct is produced, such as in OSB, smaller increases result. In products such as cellulosic fiberboard that use residues (i.e., low-value coproducts) from other manufacturing processes (i.e., lumber), there is a decrease in environmental burdens under the economic allocation approach because the burdens assigned to the residues of lumber production are reduced when based on economic value.

The allocation method had only a modest impact on the cellulosic fiberboard results. This may be surprising considering that sawmill residues (chips and shavings) are a major raw material used and very different burdens are assigned to these residues, depending on the allocation decision (Table 4). There are two explanations. First, not all of the raw materials for cellulosic fiberboard are residues; chips from whole logs and postconsumer waste, which make up 41 percent by mass of the inputs, carry with them the same environmental impact burdens regardless of whether economic or mass allocation is used. Second, the manufacturing stage of cellulosic fiberboard production is relatively important in terms of environmental impacts compared with the forest operations and wood residue production stages (as it is for many wood products), and this reduced the relative impact of changes in the environmental impact burdens associated with the raw material inputs. For example, forest operations, wood residue production, and cellulosic fiberboard life-cycle stages consumed 50.1, 534, and 6,690 MJ and emitted 3.24, 21.0, and 271 kg CO_2 eq per m^3 of cellulosic fiberboard produced (Puettmann et al. 2016a). Therefore, even if there are large differences for the impact category values in the wood residue production stage based on the two allocation approaches, the overall (cradle-to-gate) differences are minor, as illustrated in Table 3.

Impacts for OSB production increased about 7 percent when an economic allocation approach was used (Table 3). The consistent increase in environmental impacts for OSB when applying economic allocation may be surprising given that OSB is made from a single raw material product (logs harvested for OSB), there are very few coproducts that leave the production facility, and the environmental burdens associated with any coproduct used internally are ''added'' back to the main product. However, some coproducts do leave the system: survey data indicated that about 11 percent of the hog fuel produced was sold. The mass of these hog fuel residues is proportionately greater than their market value; thus, environmental burdens are shifted (slightly) to the OSB product.

Table 4.—Residues used for cellulosic fiberboard production, showing proportion of environmental burden carried forward from lumber production.

Residue	Mass balance of wood inputs (%)	Proportion (%) of lumber's burden carried forward	
		Mass allocation	Economic allocation
Canadian green chips from lumber[a]	11	24	12
Canadian dry shavings from lumber[b]	13	10	<1
Southeast green chips from hardwood lumber	2	19	9
Southeast green chips from softwood lumber	33	31	14
Chips from whole logs	26	NA[c]	NA
Postconsumer waste	15	NA	NA
Total	100		

[a] Based on Milota (2015b).

[b] Based on Bergman (2015b).

[c] NA = not applicable.

Of the three products considered for comparison, the plywood LCIA results were those most affected by the allocation approach applied. Plywood manufacture includes several steps in which a significant mass of coproducts is generated. In some cases, the relative value of the coproduct to the product is high, such as veneer that is sold rather than used to make plywood on-site. However, in other cases, the coproduct is of much lower value than the main product, such as the peeler core. In no case are the coproducts more valuable than the main product that ends up in the final plywood; thus, economic allocation associates more of the input and environmental consequences (about 25% more) on the plywood product than does mass allocation.

The allocation decision is an important one and thus has been widely discussed by LCA practitioners. Ardente and Cellura (2012) provided a review of economic allocation in LCA and concluded that it is more rational in systems producing low-value but high-quantity by-products. This could be the case in lumber production, which results in a large volume of low-value residues (chips and sawdust). A recent LCA study of softwood lumber assigned a 50 percent allocation to the lumber using a mass allocation and 86 percent under an economic allocation (Milota 2015a). The result was a 33 percent increase in the global warming (GW) impact category under the economic allocation approach. Another example was provided by Reed et al. (2012) in their study of wood pellet production. Using an economic allocation approach, there was a significant decrease in GW (from 19.8 to −18.3 g CO_2 eq/MJ). In this case, the main feedstock input for pellet production was residues from hardwood flooring production. When an economic allocation approach was applied to the hardwood flooring production process, the economic value of the residues carried much lower environmental burdens into pellet production. In these examples, an economic allocation approach seems sensible: lumber and flooring are not produced for making residues—that these residues can be used to advantage for other products is a fortunate and relatively recent development. In the past, when there was no market for these residues, they were simply burned or landfilled.

However, one potential drawback to the economic allocation approach for wood products is the uncertainty introduced given large fluctuations in product values over time (Fig. 1). Over 20 years, lumber prices varied from a low of $203 to a high of $423 per thousand board feet. This fluctuation would significantly affect the environmental burdens assigned to the lumber product, and the coproducts (e.g., chips and dust) that go into other products. The mass of products and coproducts for wood products has been relatively stable (Milota 2015a, 2015b; Bergman and Alanya-Rosenbaum 2016a, 2016b, 2017a, 2017b; Puettmann et al. 2016a, 2016b, 2016c; Bowers et al. 2017a, 2017b). Thus, an economic allocation approach will provide results that could change significantly between successive studies, depending on the prices at the time of the study. This may unfairly indicate differences among similar products for which the LCAs were completed at different times.

In addition to price variability over time, pricing data can be uncertain and/or very difficult to access for some products, adding to the potential uncertainty. The manufacturing facilities that provide survey data are generally not willing to disclose pricing information, so industry trade publications are the primary resource. However, low-value coproduct pricing can vary considerably based on its final use and proximity to the customer. Chips can be sent to the pulp mill, be sold as landscape materials, or serve as feedstock inputs for nonstructural panel products. In addition, there are many wood products where the main product pricing is not published (e.g.. glued-laminated timber, laminated veneer lumber, and I-joists). In the case of cellulosic fiberboard presented here, a lack of data prevented the consideration of coproducts in the economic allocation scenario. Cellulosic fiberboard manufacture includes the production of wood molasses, which can be used for fuel,

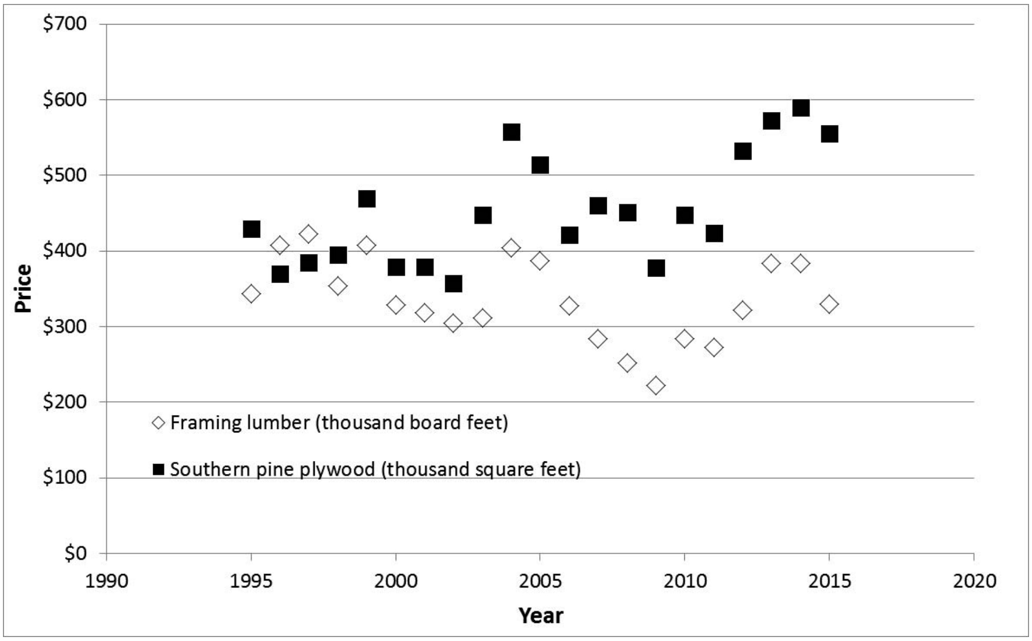

Figure 1.—Price history for lumber and plywood, nominal prices.

for additives (e.g., in papermaking), and for animal feed (Muzzy et al. 1983, Ståhl et al. 2016). The recovery of wood molasses depends on its market value, which is uncertain, as it can range from \$33 to \$165 per ovendried tonne (Bungay 1982, Muzzy et al. 1983). No pricing data on wood molasses were provided by the surveyed cellulosic fiberboard facilities (Bergman 2015b), and published data were not available. Because of this uncertainty of pricing for wood molasses, a lack of survey pricing data, and the relatively low mass compared with cellulosic fiberboard, none of the coproducts, including wood molasses, were assigned an economic value. Because these coproducts were assumed to have no value, this resulted in all environmental impacts being assigned to the cellulosic fiberboard product. If pricing data were available for these coproducts (i.e., a value greater than zero), then this would decrease the environmental impacts assigned to the cellulosic fiberboard product.

Another challenge to economic allocation for wood products is establishing the system boundary for raw materials from the forest. For example, one could argue that the harvest of OSB logs (or pulpwood) is itself a (relatively low-value) coproduct of management for saw or veneer logs. Under an economic allocation scenario, the burdens would then have to be allocated among the various log products, which potentially are harvested over many years. This would greatly increase the complexity of the LCA model versus a mass-based allocation.

Other sectors, including bioenergy, struggle with the allocation method issue (Ayer et al. 2007, Svanes et al. 2011). Luo et al. (2009) compared environmental burdens associated with bioethanol production from corn stover against gasoline production. The difference in the LCA results from the application of different allocation methods was found to be significant, where use of economic allocation led to an increase in the GW impact but reduced other impacts. For the metal sector, the production of copper, gold, platinum, and palladium occur within the same multiproduct system; thus, allocation is very complex. More copper is produced, but the price for gold is relatively high, and this has a dramatic influence on the LCA results when modeled using different allocation methods. Sandilands and Sullivan (2014) showed that the GW impact using a mass allocation approach was higher for copper (4,806 kg CO_2 eq vs. 15 kg CO_2 eq for gold), while under the economic allocation approach, the proportions were nearly reversed (4,935 kg CO_2 eq for gold vs. 192 kg CO_2 eq for copper). These LCIA results were consistent with the food and concrete sectors (Chen et al. 2010, Gac et al. 2014), where high-mass or high-value coproducts result in substantial differences between mass and economic value allocation methods.

Jungmeier et al. (2002a, 2002b) evaluated the methodological procedures used to address the multifunctionality issues in production of wood-based products and discussed the alternatives, i.e., mass, volume, economic allocation, and system expansion. The authors concluded that avoiding allocation by system expansion is the best option, but, if allocation cannot be avoided, they suggested that different allocation methods be documented. Jungmeier et al. (2002b) evaluated examples for the different allocation methods and suggested mass (or volume) for forestry activities and mass or economic allocation for primary and secondary wood product manufacturing. As mentioned above, these different allocation approaches were used in the recent updates to US wood products; LCA results were reported for both economic (as required by the PCR; FPInnovations 2015) and mass (consistent with prior studies) allocation assumptions.

Conclusions

Economic allocation in the LCAs of wood panel products results in increased environmental impacts being associated with the main product. The magnitude of the shift in environmental burdens—versus the traditional mass allocation approach—varies significantly with the product, its raw material type, and the nature of the coproducts. An economic approach has some logical advantages in wood product production where low-value, high-volume coproducts are common; however, the uncertainty and lack of availability of pricing data are significant challenges.

Allocating or assigning environmental impacts is a complex process for multiproduct systems. Thus, the selection of an allocation procedure has been found to be one of the most debated methodological problems in LCA, largely because it can notably affect the LCIA results (Weidema 2001, Reap et al. 2008, Pelletier et al. 2015, Salas et al. 2016) This is likely to be an ongoing issue because of the requirements to periodically update environmental product declarations along with the underlying LCIA results (ISO 2006c). Therefore, careful consideration by all stakeholders will be required for future revisions of the PCRs for North American structural and architectural wood products to ensure that the best allocation method (or mix of methods) for wood products is specified. In the meantime, the authors suggest the continued practice of reporting LCIA results for wood products using both mass and economic allocation approaches.

Note from Authors

This article supersedes any previously (recently) reported LCI flows and LCIA outcomes on wood panel production in the United States, including Bergman et al. (2016).

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are the authors' and do not necessarily reflect the policies and views of USDA, DOE, or ORAU/ORISE.

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