Avoiding Allocation in Life Cycle Assessment Revisited

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The problem of coproduct allocation has remained one of the most controversial issues in life cycle assessment (LCA), as can be seen from the discussions during the development of the United Kingdom's Publicly Available Specification on carbon footprinting (PAS 2050);[1] the Greenhouse Gas (GHG) Protocol for Product Life Cycle Accounting & Reporting, developed by the World Resources Institute and the World Business Council on Sustainable Development;[2] and the draft guidance document from the EU Platform on LCA (ILCD 2009).

With system expansion, the affected unit processes are scaled up or down, but there is no artificial partitioning, and because the resulting systems are simple sums of the affected unit processes, each of which maintains its physical balances intact, the resulting systems also have all physical balances intact.

We therefore revisit the issue, stressing a key argument for system expansion that has not yet been adequately described in the scientific literature—namely, that allocated systems nearly always fail to maintain mass and energy (and carbon) balances, whereas system expansion by its nature always ensures that mass and energy balances are maintained intact. We also refer to the article by Suh and colleagues (2010) in this issue of the *Journal of Industrial Ecology* (*JIE*), which paves the way for LCA databases to provide equal support for system expansion and any desired allocation key, thus eliminating the excuse that data for system expansion are not available.

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Carbon Balance

First, let us expand on an underilluminated issue—namely, that of the (lack of) ability of allocation procedures to preserve carbon balances (as well as mass and energy balances in general). The chosen system boundaries are likely correct if, first, the mass and energy balances are correct and, second, the balances for elements such as carbon are correct. In this context, *correct* means zero—that is, what comes in must go out, when one takes into account use and build-up of stocks.

Here, it is interesting to note that system expansion always ensures mass and energy balances, whereas allocation nearly always fails this test. In brief, allocation breaks up the original system into two or more artificial systems according to an allocation key, and the only balance that remains intact in the resulting systems is that given by the allocation key. With mass allocation, the mass balance remains intact, but energy and elemental balances are skewed; with economic allocation, none of the physical balances remains intact except if by chance a physical parameter follows the price of the products. With system expansion, the affected unit processes are scaled up or down, but there is no artificial partitioning, and because the resulting systems are simple sums of the affected unit processes, each of which maintains its physical balances intact, the resulting systems also have all physical balances intact.

Table 1 Obtaining two single-output systems, meat and milk, from the multi-output system "dairy cow" by allocation or system expansion

	Original systems		*System expansion*		*Dry matter allocation*		*Economic allocation*	
	Dairy cow (1)	*Meat cattle (2)*	*Milk = dairy cow – meat cattle (3)*	*Meat = Meat cattle (4)*	*Milk 81% (5)*	*Meat 19% (6)*	*Milk 77% (7)*	*Meat 23% (8)*
Feed DM	100.0	26.0	74.0	26.0	81.0	19.0	77.0	23.0
Milk DM	−9.3		−9.3		−9.3		−9.3	
Meat DM	−2.2	−2.2		−2.2		−2.2		−2.2
CH_4	−2.0	−0.5	−1.5	−0.5	−1.6	−0.4	−1.5	−0.5
Manure DM	−23.2	−4.7	−18.5	−4.7	−18.8	−4.4	−17.9	−5.3
C in CO_2	−28.3	−8.1	−20.2	−8.1	−22.9	−5.4	−21.8	−6.5
Respiratory water	−35.0	−10.5	−24.5	−10.5	−28.4	−6.6	−27.0	−8.1
Mass balance	0.0	0.0	0.0	0.0	0.0	0.0	−0.4	0.4
Feed C	46.5	12.0	34.5	12.0	37.66	8.84	35.8	10.7
Milk C	−5.3		−5.3		−5.3		−5.3	
Meat C	−1.0	−1.0		−1.0		−1.0		−1.0
CH_4-C	−1.5	−0.4	−1.1	−0.4	−1.22	−0.29	−1.2	−0.3
Manure C	−10.4	−2.2	−8.2	−2.2	−8.42	−1.98	−8.0	−2.4
C in CO_2	−28.3	−8.4	−19.9	−8.4	−22.92	−5.38	−21.8	−6.5
C balance	0.0	0.0	0.00	0.0	−0.2	0.2	−0.5	0.5

Note: DM = dry matter; CH_4 = methane; C = carbon; CO_2 = carbon dioxide.

Let us take a well-known example: A system with one feedstock input, feed, and two product outputs, milk and meat. For convenience, we may call the system "dairy cow." A few facts about the system are given in the first column of table 1. If we use the dry matter input of feed as a reference, this dry matter leaves the system as follows: 9.3% is milk and 2.2% is meat; 2.0% is emitted as methane; 23.2% leaves the system as manure, which, for simplicity, we treat as a waste in this example; 28.3% leaves the system as carbon in respiratory carbon dioxide (CO_2); and 35% is emitted as respiratory water. It may seem illogical that a dry matter balance contains water, but this is due to the nature of the feed input (roughly $C_6H_{12}O_6$), which releases water as part of the system metabolism. The carbon contents of feed, milk, meat, and manure are 46.5%, 57.0%, 44.0%, and 45.0%, respectively, on a dry matter basis. We thus have 46.5% carbon input in feed, which leaves the system with 5.3% in milk and 1.0% in meat, 1.5% in methane, 10.4% in manure, and 28.3% in respiratory CO_2.

For system expansion, we need the additional system "meat cattle," which is displaced by the additional output of meat from the dairy cow. The mass and carbon balances for meat cattle are given in column 2 of table 1, scaled to the output of meat from the dairy cow in column 1. System expansion implies that the original dairy cow is assigned entirely to the determining product—that is, the milk system—and that one must subtract the production of the corresponding amount of dependent by-product—that is, the meat from the alternative production route, the system "meat cattle." The meat system is exclusively assigned the meat cattle route; that is, in the expanded system, no meat comes from the dairy cow. Because both dairy cow and meat cattle are systems with complete mass, energy, and elemental balances, these balances are also maintained in the resulting single-product systems, as can be seen in columns 3 and 4 in table 1.

If we instead use an allocation key to partition the dairy cow, columns 5 to 8 in table 1 shows what happens:

- If we use the dry mass of the outputs as allocation key, we will obtain a partitioning of the inputs and outputs of the dairy cow with a ratio of 81.0% to the milk and 19.0% to the meat. The system "milk" will thus have an input of 81.0% of the feed. Exactly because *mass* is the allocation key, the *mass* balances of the allocated systems are correct. Carbon in and out do not balance, however: Of the 46.5% carbon into the dairy cow, 37.66% enters the milk system, but 37.86% leaves the system, for an imbalance of 0.2%. Similarly, the meat system has 8.84% in but 8.64% out.
- If we use the economic value of the output as the allocation key, we will obtain a partitioning of the inputs and outputs of the cow with a ratio around 77.0% to the milk and 23.0% to the meat, depending on local market conditions. Table 1 clearly shows that neither mass nor carbon balances are maintained. The only balance that fits is the economic one: The milk system has 77.0% of the income from product sales and 77.0% of the expenditures for feed inputs.

We have on purpose chosen an example in which the imbalances are small. We could easily find more extreme examples—for example, we might use wet mass as an allocation key or use economic allocation on a product system for which the relative prices of the coproducts deviate more from the relative masses (e.g., high-quality timber and wood residuals for pulp or biofuel). The examples above, however, should be adequate to illustrate the point: The only balance that remains intact in allocation is the balance of the allocation key.

Likewise, we could easily find more complicated examples of system expansion, in which more processes come into play, such as transport, intermediate treatments, downstream differences between the displacing and displaced products, and displaced products with further coproducts, as described by Weidema (2001a, 2001b, 2003). In all such cases, however, we still operate with fully intact processes that are simply scaled up or down. Because there is no partitioning, mass, energy, or elementary balances will always remain intact.

System Expansion in LCA Databases

It is interesting to note that the two technology models most widely used by input–output economists to convert supply–use matrices into direct requirement matrices are identical to the two methods for coproduct allocation most favored by LCA practitioners—namely, economic allocation and system expansion (Suh et al. 2010). The industry technology model (so called because it assumes that all products produced by an industry have identical inputs and outputs per monetary unit) uses the proportional value of the coproducts as the allocation key—that is, identical to the economic allocation of LCA. Applying the commodity technology model (so called because it assumes that each commodity is produced by a unique technology, with the same inputs and outputs, irrespective of which industry it is produced in) gives the same results as applying system expansion in LCA, where the inputs and outputs for the main product result from subtracting the inputs and outputs that relate to the production of the by-product from its alternative (main or marginal) production route.

Thus, if an LCA database stores process data unallocated in a format corresponding to supply–use tables, any desired technology model can be applied to these unallocated data, and the database is just as applicable for producing analytical models with system expansion as analytical models with any desired allocation key.

Conclusion

We restate the main arguments for the ISO 14044 (ISO 2006) requirement for applying system expansion whenever possible: Only system expansion consistently fulfils the two further requirements of ISO 14044—that all significant processes that are affected should be included, in this case by a change in the amount of coproducts, and that all systems should yield comparable product outputs, which is ensured in system expansion by subtraction or balancing of the processes that provide product outputs that do not occur in all of the compared systems. As Weidema (2001a, 2001b) noted, these two important requirements are, in general, not fulfilled by allocation. First, allocation does not consider the extent to which a change in the amount of the coproducts affects the functional output and other exchanges of the coproducing process. Second, allocation ignores the effects that a coproduct may have on the further fate of the other coproducts—that is, displacement effects and additional treatment of the coproducts before displacement takes place. Thus, traditional coproduct allocation only fulfills the above two requirements in those particular instances in which the allocation factors are chosen to reflect the way the coproducts actually affect the coproducing process and in which there are no significant effects on the further fate of the other coproducts. In such instances, allocation may be regarded as a special instance of system expansion. The availability of hybrid LCA databases with consistent implementation of system expansion, according to the models provided by Suh and colleagues (2010), resolves the problem of data for system expansion.

Notes

1. www.bsigroup.com/Standards-and-Publications/How-we-can-help-you/Professional-Standards-Service/PAS-2050
2. www.ghgprotocol.org/

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