Using Exergy Analysis for Improving Life Cycle Inventory Databases

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Many efforts have focused on developing life cycle inventory (LCI) databases of various industrial processes. Collected data are reported in disparate units and obtained from different sources that may be outdated, unreliable, incomplete and/or unverifiable (Ayres, 1995). As a result, such inventories tend to be inconsistent, unrealistic and even physically impossible, i.e. they violate the laws of conservation of energy and mass as well as the second law of thermodynamics. A chemical engineering-based approach for gate-to-gate LCI has been proposed to partially overcome these shortcomings (Jiménez-González et al., 2000). The proposed approach is further used to develop sub-modules that facilitate easy and consistent evaluation of processes, especially in early stages of design or when information about processes in the supply chain is not available (Jimenez-Gonzalez and Overcash, 2000). Furthermore, the use of engineering principles ensures satisfaction of basic laws such as conservation of mass and energy. Unsolved issues in this approach are that data are still reported in disparate units and it has not been made clear how to complete, validate or reconcile existing databases. Moreover, connection of these sub-modules with others at different scales and levels of aggregation such as economy and ecosystem is not straightforward.

Exergy or *Available energy* is the maximum amount of *work* that can be extracted when a system is brought to equilibrium with its surroundings, that is by means of reversible processes (Szargut et al., 1988). For instance, the exergy of a heat stream is the work that can be extracted in a reversibly-operated thermal engine, i.e. the fraction of the stream's heat content determined by the *Carnot efficiency factor*. Exergy is a better measure of the quality of energy than energy because it only accounts for the energy that can be converted into work. Additionally, in real processes, exergy is not conserved; on the contrary, it is consumed or lost throughout the process. This measurement of exergy lost or consumed constitutes a powerful indicator of performance in the process. It has been used in engineering to identify and improve the causes of thermal imperfection in process units (Szargut et al., 1988).

Exergy analysis is a promising method for analyzing and improving sustainability of industrial activities. Advantages of implementing exergy analysis in the improvement of Life Cycle Inventory databases are described below.

- Since it is consumed or lost in all real processes, exergy can help to complete, validate and reconcile existing databases and further connect them to sub-modules at other scales and levels of aggregation. As mass and energy flows must be conserved in order to assure consistency, exergy must be lost (conservation of exergy only apply for reversible processes), i.e. exergy inflow must be larger than exergy outflow. This fact can be very helpful in completing inventories. For instance, many inventories may have been reconciled by using the equations of conservation of mass and energy. However, such approach is incomplete because it does not assure that the resulting inventory is feasible. On the other hand, an exergy balance must have a term that represents the exergy loss in the system. A negative exergy loss indicates that there is a violation of the second law of thermodynamics and therefore the inventory is unrealistic. This result may suggest that there is missing data, that there are streams being neglected or that some values are underestimated. It is possible to estimate the missing values by assuring that the exergy balances in the system do not show negative losses. The same criterion can be used to connect various sub-modules consistently.

- Having separate measures for energy and mass of a stream may be confusing and introduce redundancy to the analysis. For example, fuels may be tabulated by their energy content and by their mass flow. It is possible that in the process of merging data from different sources, a fuel stream is accounted for twice. One of the most attractive features of exergy analysis is that it provides a scientifically rigorous way of converting all types of material and energy streams into a common currency. This permits convenient interpretation and manipulation of the process information, eliminating the risk of double counting. It also helps in identifying opportunities for improving process efficiency by allowing a clear comparison between energy and mass flows.

- Exergy analysis and its extensions such as ecological cumulative exergy consumption (ECEC) (Hau and Bakshi, 2004) also permit expansion of the Life Cycle Inventory to include the contribution of ecological goods and services. Such expansion is essential for life cycle and sustainability analysis. If economic information about each sub-module is available, it can be used to expand the analysis boundary by including the exergetic contribution and emissions from the economic network (Ukidwe and Bakshi, 2004).

- In the absence of detailed impact assessment, the exergy of emissions or their ecological cumulative exergy consumption (Hau and Bakshi, 2004) can act as proxies for the potential impact of the emissions.

This work presents a method to incorporate exergy analysis in existing life cycle inventories. Such combination is used to overcome many of the shortcomings that LCI faces. The extra information required for exergy analysis and benefits of this approach are discussed and demonstrated via applications to a typical refinery. Results show that exergy analysis can strongly complement Life Cycle Assessment and evaluation of sustainable processes and products.

References

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