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Input-Output Supply Chain Modeling *and* the Computational Structure *of* LCA-type Costing

Ettore Settanni, Giuseppe Tassielli and Bruno Notarnicola
Department of Commodity Science – University of Bari, Italy

Overview

- ✓ Life Cycle Assessment, Costing and the Supply Chain
  - cost issues in LCA
  - the practical implementation constraints
  - the “supply chain” meaning of life cycle
- ✓ Input-Output modeling and costing
  - materials flow modeling and enterprise Input-Output Accounts
  - proposal for a LCA-type computational structure
- ✓ Final remarks and need for further developments

1. Life Cycle Assessment, Costing and the Supply Chain
- Cost issues in LCA

- Emerging trend to integrate Management Accounting and Environmental Management systems and analytical tools
- Life Cycle Costing (LCC) has been considered a tool to be used within Life Cycle Management (LCM) as the "economic counterpart" of Life Cycle Assessment (LCA)
- LCC concept has been originally intended as an asset management tool which:
  - ✓ recognizes that most of the costs which will be incurred are committed in the design phase of a product;
  - ✓ is grounded on a life-cycle concept which is not the same of LCA;
  - ✓ does not necessarily take into account physical flows and environmental interventions as cost drivers.
- Diverging outcomes of separate LCC and LCA would force to set either environmental or economic priorities unless not easily quantifiable cost issues are included or a discount rate is quite arbitrarily chosen

1. Life Cycle Assessment, Costing and the Supply Chain
- Cost issues in LCA

- A formal integration of LCC into LCA seems to be excluded
- Most of the proposed models combine some discounted cash flows analysis with LCA (parallel implementation).
- A formal cost accounting method is needed which allows considering, in a straightforward way, the repercussions on production costs induced (i.e. *driven*) by the management of the relevant operations and physical flows (resources consumption and pollutant emissions) along the value chain .
- Such a method is required to be *dual*, i.e. to integrate physical and monetary issues within a shared computational structure which is grounded on the well established one of Life Cycle Inventories.

1. Life Cycle Assessment, Costing and the Supply Chain
- The practical implementation constraint

- If the cost accounting system is going to play a role in LCA, it will:
  - ✓ provide those actors which are expected to actually interact and jointly reduce environmental burdens with *specific* cost figures that support decisions on how to cooperate, once they are made aware of the environmental consequences of their products;
  - ✓ identify both cost drivers and environmental interventions which can be actually controlled in order to put the outcomes of an LCA into operation and to gain insights on how this would cost as well;
  - ✓ help reduce information asymmetry between the buyer and the supplier regarding the relationship between the specifications established by the former and the resulting costs to the latter, in order to identify opportunities for joint cost reduction (interorganizational cost management).

1. Life Cycle Assessment, Costing and the Supply Chain
- The Supply Chain meaning of Life cycle

- An Integrated or Green Supply Chain (SC) perspective seems consistent with an LCA’s “physical” from-cradle-to-grave life-cycle and shares its conceptual basis
- The emphasis is on material and information flows management
- It recognizes that joint reduction of environmental impacts and costs requires multiple actors cooperation (supplier, producer, user and end-of-life actor)
- A method for cost accounting in a Supply Chain perspective combines the perspective of the actors also when dealing with the additional environmental requirements that must be met at each stage and often drives up costs.
- A concept of LCC sharing LCA-type computational structure will seek for cost savings beyond the influence of a single company achieving the interconnected links of materials and information flows

2. Input-Output Modeling and Costing

- Materials flow modeling and Enterprise Input-Output Accounts

- Input-Output Supply Chain Modeling provides a description of the interdependencies among a set of production processes which are performed by supply chain actors

- The choice of sequential processes linked by supplier/customer relationships defines the system boundaries and the scope of the analysis.

- Accounting for:
  - ✓Economic flows: main outputs, externally purchased inputs, waste/byproduct,
  - ✓Environmental flows
  - ✓Primary factors or Conversion Cost drivers (other than the former physical flows)

2. Input-Output Modeling and Costing

- proposal for a LCA-type computational structure

- The first goal to achieve is to make the focus company aware of both the physical flows which characterize its manufacturing processes as well as the cost of processes inefficiencies such as wastes, scraps, byproducts.

- Relevant physical inflows (minus sign) and outflows (plus sing) are collected with reference to each unit process according to its own technical specifications like capacity, batch size and cycle time (a kind of “cooking recipe”) and arranged as a column vector entries.

- Parametric issues: different batches of products may require different interrelated processes to operate according with different parameters, due to design specifications. Resources and time consumption vary accordingly.

2. Input-Output Modeling and Costing

- proposal for a LCA-type computational structure

Further steps:

- Implement a cut off algorithm to organize the collected data
  - ✓ it has the same meaning as in LCA;
  - ✓ yet, from a cost accounting perspective the aim of reducing cut off depends upon the feasibility of strategic cost management among supply chain partners

- An allocation procedure allows to apply joint product costing and to calculate, though arbitrarily, both the cost of producing a waste/byproduct and the incurred disposal/treatment cost:

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- proposal for a LCA-type computational structure

Physical flows	*Units*	***Processes***				
Main products		$\hat{v}^T_{11}$	$-u_{12}$	$-u_{1i}$	$-u_{1j}$	$-u_{1n}$
(Net output matrix)		$-u_{21}$	$\hat{v}^T_{22}$	$-u_{2i}$	$-u_{2j}$	$-u_{2n}$
		$-u_{i1}$	$-u_{i2}$	$\hat{v}^T_{ii}$	$-u_{ij}$	$-u_{in}$
		$-u_{j1}$	$-u_{j2}$	$-u_{ji}$	$\hat{v}^T_{jj}$	$-u_{jn}$
		$-u_{n1}$	$-u_{n2}$	$-u_{ni}$	$-u_{nj}$	$\hat{v}^T_{nn}$
Net waste generation		$\overline{n}^T_{11}-\underline{n}_{11}$	$\overline{n}^T_{12}-\underline{n}_{12}$	$\overline{n}^T_{1i}-\underline{n}_{1i}$	$\overline{n}^T_{1j}-\underline{n}_{1j}$	$\overline{n}^T_{1n}-\underline{n}_{1n}$
• by-products or co-products • wastes and effluents		$\overline{n}^T_{k1}-\underline{n}_{k1}$	$\overline{n}^T_{k2}-\underline{n}_{k2}$	$\overline{n}^T_{ki}-\underline{n}_{ki}$	$\overline{n}^T_{kj}-\underline{n}_{kj}$	$\overline{n}^T_{kn}-\underline{n}_{kn}$
• input of waste		$\overline{n}^T_{n_w1}-\underline{n}_{n_w1}$	$\overline{n}^T_{n_w2}-\underline{n}_{n_w2}$	$\overline{n}^T_{n_wi}-\underline{n}_{n_wi}$	$\overline{n}^T_{n_wj}-\underline{n}_{n_wj}$	$\overline{n}^T_{n_wn}-\underline{n}_{n_wn}$
Externally Purchased inputs		$-m_{11}$	$-m_{12}$	$-m_{1i}$	$-m_{1j}$	$-m_{1n}$
		$-m_{21}$	$-m_{22}$	$-m_{2i}$	$-m_{2j}$	$-m_{2n}$
		$-m_{n_M1}$	$-m_{n_M2}$	$-m_{n_Mi}$	$-m_{n_Mj}$	$-m_{n_Mn}$
Labor cost drivers		$-l_{11}$	$-l_{12}$	$-l_{1i}$	$-l_{1j}$	$-l_{1n}$
		$-l_{21}$	$-l_{22}$	$-l_{2i}$	$-l_{2j}$	$-l_{2n}$
		$-l_{n_L1}$	$-l_{n_L2}$	$-l_{n_Li}$	$-l_{n_Lj}$	$-l_{n_Ln}$
Overhead cost drivers		$-h_{11}$	$-h_{12}$	$-h_{1i}$	$-h_{1j}$	$-h_{1n}$
		$-h_{21}$	$-h_{22}$	$-h_{2i}$	$-h_{2j}$	$-h_{2n}$
		$-h_{n_H1}$	$-h_{n_H2}$	$-h_{n_Hi}$	$-h_{n_Hj}$	$-h_{n_Hn}$
Net environmental flows		$\overline{r}^T_{11}-\underline{r}_{11}$	$\overline{r}^T_{12}-\underline{r}_{12}$	$\overline{r}^T_{1i}-\underline{r}_{1i}$	$\overline{r}^T_{1j}-\underline{r}_{1j}$	$\overline{r}^T_{1n}-\underline{r}_{1n}$
		$\overline{r}^T_{21}-\underline{r}_{21}$	$\overline{r}^T_{22}-\underline{r}_{22}$	$\overline{r}^T_{2i}-\underline{r}_{2i}$	$\overline{r}^T_{2j}-\underline{r}_{2j}$	$\overline{r}^T_{2n}-\underline{r}_{2n}$
		$\overline{r}^T_{n_E1}-\underline{r}_{n_E1}$	$\overline{r}^T_{n_E2}-\underline{r}_{n_E2}$	$\overline{r}^T_{n_Ei}-\underline{r}_{n_Ei}$	$\overline{r}^T_{n_Ej}-\underline{r}_{n_Ej}$	$\overline{r}^T_{n_En}-\underline{r}_{n_En}$

Compact matrix notation

$$\begin{bmatrix} Z \\ W \\ -M \\ -L \\ -H \\ R \end{bmatrix} = \begin{bmatrix} \hat{V}^T \\ \overline{N}^T \\ 0 \\ 0 \\ 0 \\ \overline{R}^T \end{bmatrix} - \begin{bmatrix} U \\ \underline{N} \\ M \\ L \\ H \\ \underline{R} \end{bmatrix}$$

Assumptions:

Process *j* produces commodity *j* as its main output;

$i \neq j \rightarrow \hat{v}_{ij} = 0$

$\forall j \in n, \forall k \in n_w : \overline{n}_{jk} \times \underline{n}_{kj} = 0$

All data expressed in physical units

2. Input-Output Modeling and Costing

- proposal for a LCA-type computational structure

Further steps:

- Set an exogenous reference flows: it could be a batch of a given product.
- Implement Balancing procedure:
  - ✓ it yields the activity levels at which processes are required to operate in order to meet the reference flow

$$\left(\breve{V}^{T}-U\right)\times s_{I}=y_{I}\Rightarrow s_{I}=\left(\breve{V}^{T}-U\right)^{-1}y_{I}$$

  - ✓ all the recorded flows, including cost drivers, are rearranged and "scaled up" i.e. balanced.

$$\begin{bmatrix} \breve{V}^{T}-U \\ 0 \\ \hline \overline{N}^{T} \\ -B \\ \overline{N}^{T} \\ -\underline{N} \\ R \end{bmatrix}\hat{s}_{I}e=\begin{bmatrix} \tilde{\breve{V}}^{T}-\tilde{U} \\ 0 \\ \hline \tilde{\overline{N}}^{T} \\ -\tilde{B} \\ \tilde{\overline{N}}^{T} \\ -\underline{\tilde{N}} \\ \tilde{R} \end{bmatrix}e=\begin{bmatrix} y_{I} \\ 0 \\ \hline \varepsilon \\ \upsilon \\ \varepsilon \\ \rho \\ g \end{bmatrix}$$

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Further steps:

- Turn out the waste flows into the demand for their end-of-pipe treatment. (waste flows are aggregated according to the treatment they undergo.

$$\begin{bmatrix} I & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & I & Q(I-\hat{r}) & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & I & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \hat{r} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & I & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & I \end{bmatrix} \times \begin{bmatrix} \tilde{V}^T - \tilde{U} \\ 0 \\ \tilde{\tilde{N}}^T \\ -\tilde{B} \\ \tilde{\tilde{N}}^T \\ -\tilde{\tilde{N}} \\ \tilde{R} \end{bmatrix} = \begin{bmatrix} \tilde{V}^T - \tilde{U} \\ -Q(I-\hat{r})\tilde{\tilde{N}}^T \\ -\tilde{B} \\ \hat{r}\tilde{\tilde{N}}^T \\ -\tilde{\tilde{N}} \\ \tilde{R} \end{bmatrix}$$

✓ The amount of waste which undergoes treatment processes is net of the sale of waste. The latter is the amount which serve as secondary input for other processes within the Supply Chain

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Further steps:

- Obtain the complete “physical grid” including those treatment processes which are run internally
  - ✓ determine the activity level of treatment processes
  - ✓ re-scale the flows which refers to them
- This yields the matrix on which costing will be carried out

$$\left[\begin{array}{cc} \breve{V}^{T}{}_{I,I} - \tilde{U}_{I,I} & 0 \\ -Q(I-\hat{r})\overline{\tilde{N}}^{T}_{\bullet,I} & \breve{V}^{T}_{II,II} \\ \hline -\tilde{B}_{\bullet,I} & -\tilde{B}_{\bullet,II} \\ \hat{r}\overline{\tilde{N}}^{T}_{\bullet,I} & 0 \\ -\underline{\tilde{N}}_{\bullet,I} & 0 \\ \tilde{R}_{\bullet,I} & \tilde{R}_{\bullet,II} \end{array}\right]$$

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- The physical input-output relationship are to be converted into financial relationships among different units within a company and between the company and the outside market.

- To the purpose, the Supply Chain of relevant unit processes must be seen as a vertically integrated firm.

- Process costing criteria:
  - ✓When units are finished for a process, manufacturing costs are transferred to the downstream process receiving it, as a separate category of direct material costs

  - ✓ The cost of producing each process' main output is assumed to offset the transfer price for all the inputs supplied by the other processes and the costs related to (a) externally purchased inputs, (b) waste/by products treatment and (c) inter-process recycling, (d) labor and overheads

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Costing steps:

- Obtain the equivalent of leontevian “value added vector” (although it is not a value added properly) by applying monetary values to the driver amounts which have to be available in the Input-Output balanced scheme :
  - ✓Direct material and Direct labor costs are traced to processes applying price standards to the resource consumption resulting after having scaled up flows
  - ✓ *predetermined* overhead rates are calculated (budgeted period overhead/budgeted period activity level) and *applied* according to the amount of the amount of each cost driver calculated after scaling up flows
  - ✓ the sale of waste within intra process recycling is taken into account. The price of waste is exogenous and is not necessarily the cost of producing it (since it could be also negative or zero)
  - ✓ If treatment processes are purchased externally, an exogenous market price is applied

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Costing steps:

- Pre-multiplying the obtained “value added” vector by the inverse of the net output matrix, yields a vector (Life Cycle Cost Vector) whose entries shows how manufacturing costs have been accumulated in each stage of the unit processes supply chain, included those incurred to run the treatment processes internally.

$$\Rightarrow [p_I \quad p_{II}] = [\omega_I \quad \omega_{II}] \times \begin{bmatrix} \breve{V}^T_{I,I} - \tilde{U}_{I,I} & 0 \\ -Q(I-\hat{r})\overline{\tilde{\tilde{N}}}^T_{\bullet,I} & \breve{V}^T_{II,II} \end{bmatrix}^{-1}$$

- The incurred “internal failure” environmental costs will be automatically allocated to processes according to their demand for waste treatment, if end-of-pipe treatment are run internally

3. Final remarks and need for further development

- Sustainable development will not just happen on its own. Managing relationships among partners seems crucial to put LCA into operations
- Companies increasingly face the complex competitive environment as part of a supply or value chain. Opportunities for cost savings and greater efficiencies in the use of resources often lie beyond the company gates
- The proposal method aims to
  - ✓ integrate environmental and economic flows within a formal computational structure, considering the holistic approach of the supply chain concept as the LCA approach in management accounting
  - ✓ extend the cost management scope beyond organizational boundaries
  - ✓ determine material and cost flows among well specified organizations and analyze the network of materials, energy and pollution flows and the associated interorganizational costs

3. Final remarks and need for further development

- The first aim is to offer a solution to the individual problem that has to be tackled by a certain actor.

- Then the analysis should be gradually extended to link supplier to customer in the value chain, in order to take into account and combine their own economic and environmental issues

- The method should not be deterministic: further development should address managing uncertainty issues within the model's parameters, so that that it could serve as both a backcasting and a forecasting tool

Thank you for your attention!

Reference Author:
Ettore Settanni
E-mail: **ettoresettanni@hotmail.com**
Mobile: +39 3292723015

Department of Commodity Science
Faculty of Economics
University of Bari
Via C. Rosalba, 53
70124 Bari - Italy