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# Labor and Services as Information Carriers in Emergy-LCA Accounting

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**Abstract**

Production and consumption processes in national and local economies are supported by free renewable environmental resources as well as by nonrenewable minerals and fuels. Economies measure the values of these resources in money terms. It is not always clear that money does not pay nature for providing resources, but only pays humans for extracting, processing and delivering them within markets. Emergy Accounting (EMA) is an environmental accounting method based on the recognition of the work done by nature in generating mineral and energy resources. The work of nature is accounted for in terms of solar equivalent energy supporting natural capital formation and the supply of ecosystem services. Human labor and services are also supported by solar emergy flows and contribute energy and information to economic processes. This paper discusses the role of labor in production processes and designs appropriate accounting schemes based on the emergy approach. The Life Cycle Assessment method (LCA) as well as other resource assessment schemes do not include labor and services in their accounting framework. By keeping track of environmental resources supporting labor and services, emergy provides an important and much needed contribution to a more comprehensive assessment of economic and societal dynamics.



## 1 Introduction

The traditional way of measuring economic transactions and activities uses money as a unit of account. As a consequence, resources and money are strictly related to the working time of humans in resource processing and consuming. An emergy evaluation of a production process is therefore an assessment of the links between resources available, labor displayed, and product generated.

The difference between emergy and conventional economics or other biophysical evaluations is that the emergy accounting systematically includes in the assessment of the work performed by the environment in generating resources and ecosystem services, and the work performed by humans, assigning to both of them an emergy value commensurate to the resources invested. The additional work provided by human activities in order to refine a raw resource adds to its quality by making it more suitable to the final user. It is therefore clear that what makes a resource valuable is both the environmental and human work investment, according

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to the emergy donor-side perspective.

### 1.1 Labor and societal infrastructure

The importance of labor (activity directly applied to a process) and services (activities indirectly applied to a process from the larger scale of the economy) as key factors of production processes is crucial and is often quantitatively disregarded in analyses of products and processes. Labor carries the memory of fuels, materials, food, minerals needed directly and indirectly to support the life of workers, train, transport and feed them. In a like manner, services carry a share of the total emergy supporting the societal infrastructures (health system, transport, defense, education, communications, governmental structures and so on), all needed for direct and indirect labor to fully display its potential. This is why it is important to account for labor and services in LCA and Environmental Accounting, not to risk that important and much needed contributions are disregarded and the final results affected to a larger extent.

### 1.2 Labor and information

Labor and service (L&S) inputs to a process transfer vital knowledge and information possessed by the laborer, to the production process. The problem is that the information content of that input is very difficult if not impossible to quantify as such. Instead, the amount of resources supporting the generation of information, i.e. how much it takes to support educated labor, generate innovation, make new technologies, construct infrastructures, test and spread new solutions and designs, can be quantified in emergy terms. For example, Odum (1989) explored the emergy needed to support a University system including support of undergraduate, graduate and PhD students as well as ongoing research activity. Additionally, Odum (1996) calculated average values (order of magnitudes) of emergy intensities per hour or joule of applied labor at different training and education levels in the USA economy. Campbell and Lu (2009) computed the emergy required to educated an individual with a given education level and then developed this idea further to compute the contribution ot human know-how to the economy (Campbell et al, 2011). Bergquist et al (2011) suggested that computations of the emergy of labor should include four aspects: calorie intake, quality and quantity of knowledge, and the cultural context the labor is applied. Finally, Brown et al. (2012) design a framework for joint EMA and LCA assessment of processing, with focus on time and spatial boundaries and case studies of energy generation, and provide a standardized procedure to account for direct and indirect flows of matter, energy, labor and services.

## 2 Methods, Emergy Accounting Concepts and Definitions

Human societies feed on resources extracted from the earth crust and use different kinds of ecosystem services. Odum (1988) identified natural capital and ecosystem services as the real source of wealth, in spite of the common belief that only labor and economic capital were such a source. Calculating the work performed by nature to generate the resources that we extract, process and use within our economic systems provides a measure of their “donor-side” quality, i.e. a measure of their production cost from the point of view of the biosphere, and - as a consequence - a measure of their renewability and sustainability from an environmental point of view. EMergy is defined as “the total available energy (exergy) of one kind (usually solar) directly and indirectly used up to drive a process and generate a product or a product flow” (Odum, 1996), with unit expressed as “solar equivalent joule” (seJ). All renewable and nonrenewable, local and imported input flows to a process (matter, energy, labor, money and information) are listed in an inventory and converted to emergy units by means of emergy intensity coefficients named Unit Emergy Values (UEV, sometimes named transformities or specific emergy when flows are measured respectively as energy and mass, with units of seJ/J, seJ/g, seJ/hour, seJ/$, seJ/ha). Then, the emergy flows are added into a total and several performance indicators are calculated. Geothermal and gravitational energies are converted into solar equivalents by means of conversion coefficients that take into account the complex interactions among biosphere processes. The equivalence among the different driving sources was firstly stated by Odum (1996, 2000) and updated by Brown and Ulgiati (2010), yielding the total biosphere emergy baseline (i.e. the total emergy annually driving the Earth dynamics in the form of direct insolation, deep heat and gravitational potential).

Figure 1 shows a simplified scheme of a production process, supported by renewable flows (R), minerals (Fs), goods and materials (M).

The total eMergy U supporting a system or a process is calculated according to the following equation:

$$U = \sum_{i=1}^{n} f_i \times UEV_i \tag{1}$$

where $f_i$ is the $i$th input flow of matter or energy and $UEV_i$ the emergy intensity of the $i$th flow (from literature or purposefully calculated).

Calculation procedures are, in general, organized by means of a computational table (Table 1), where columns indicate raw inputs, UEVs, emergy flows and their respective units and references. It clearly appears from Figure 1 and Table 1 that the emergy supporting the system is carried by flows of local resources, imported flows of goods and materials, and flows of labor and services, which carry into the process the information needed for the process to happen.

In emergy evaluations of national and regional economies, the link between emergy supply and economic performance is provided by the ratio of total emergy used to GDP (Gross Domestic Product), measured as seJ/currency unit. It indicates the emergy investment needed to create a unit of monetary output. The emergy to GDP ratio is used in emergy calculation procedures to convert the money inputs associated to labor and services into emergy units. Further details on the method can be found in Brown and Ulgiati (2004, 2010).

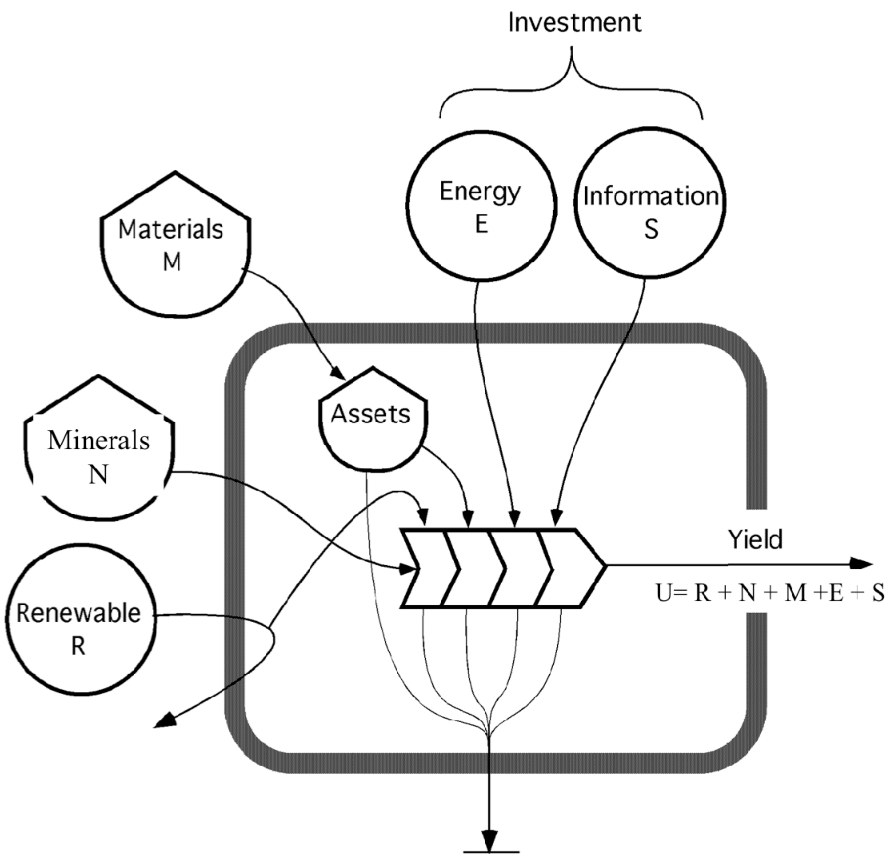


**Fig. 1.** General diagram of the production process, driven by local renewable (R) and nonrenewable (N) flows, imported goods and materials (M), energy (E) and information/know-how (S) to yield a functional product (Y). All inputs are summed to determine the emergy of the output (U). Information S is carried by direct and indirect labor (services).

**Table 1**. Template emergy table (for a generic agricultural system)

| | Item | Raw amount | Unit | UEV(seJ/unit) | Ref. of UEV | Emergy flows (seJ/ha/yr) |
|---|---|---|---|---|---|---|
| 1 | Local renewable resources | | | | | |
| 2 | Solar radiation | … | J/ha/yr | … | … | … |
| 3 | Rain (chem. potential) | … | J/ha/yr | … | … | … |
| 4 | Wind | … | J/ha/yr | … | … | … |
| 5 | Deep heat | … | J/ha/yr | … | … | … |
| | Local nonrenewable resources | | | | | |
| 6 | Soil loss (org. matter) | … | J/ha/yr | … | … | … |
| 7 | Ground water | … | g/ha/yr | … | … | … |
| | Resources from outside the system | | | | | |
| 8 | Seeds | … | J/ha/yr | … | … | … |
| 9 | Nitrogen fertilizer, N | … | g/ha/yr | … | … | … |
| 10 | Phosphate fertilizer, $P_2O_5$ | … | g/ha/yr | … | … | … |
| 11 | Potash pertilizer, $K_2O$ | … | g/ha/yr | … | … | … |
| 12 | Herbicides, pesticides, etc | … | g/ha/yr | … | … | … |
| 13 | Steel for machinery | … | g/ha/yr | … | … | … |
| 14 | Fuel for machinery (diesel) | … | J/ha/yr | … | … | … |
| | Labor and Services | | | | | |
| 15 | Management and Labor | … | $/ha/yr | … | … | … |
| 16 | Services | … | $/ha/yr | … | … | … |
| 17 | Product harvested | … | g/ha/yr | | | |
| 18 | Total Emergy, w/out L&S | … | seJ/yr | | | … |
| | Total Emergy, with L&S | … | seJ/yr | | | … |
| 19 | Transformity of product, w/out L&S | | seJ/J | … | Calculated in this work | |
| | Transformity of product, with L&S | | sej/J | … | Calculated in this work | |
| 20 | Specific emergy of product, w/out L&S | | sej/g | … | Calculated in this work | |
| | Specific emergy of product, with L&S | | seJ/g | … | Calculated in this work | |

Footnotes of items 1 to 20…

The emergy method is spreading worldwide as a suitable tool for environmental and sustainability accounting (Dong et al., 2008; Liu et al., 2013). The increased number of studies performed and papers published requires an increased standardization of the accounting procedure, for easier comparison of results and increased reliability.

## 3 Accounting for direct and indirect labor (foreground and background…)

Assessing the value of labor and services has been a crucial problem since the very beginning of energy analysis. Before going through the different aspects, it might be useful to define what we mean by labor and service, but first we need to explore the LCA concepts of foreground and background. When focusing on a whole chain of process steps, LCA divides inputs as foreground and background: "*foreground*" are those inputs that are under the control of the operator of a process (or, in other words, that are supplied directly), while "*background"* are those inputs that have been supplied in previous steps, no longer under the control of the operator (and therefore, indirectly). These are useful distinctions as related to labor and services, thus we categorize labor as being foreground inputs and services as being background inputs.

Labor is direct input of human work (direct labor) always accounted for as being a foreground input. Direct labor is accounted for as working hours or years applied and the quality of the worker (unskilled, trained, educated, etc) using Unit Emergy Values for labor based on level of training and education (seJ/person/time). In practice, however, the emergy value of direct labor is computed through the money payments for labor since calculating the emergy required to support different levels of education and training has not been done for most economies of the world. Therefore the money payments for labor are multiplied by an emergy cost factor, the Unit Emergy Value of currency (seJ/GDP) in a given year in a given economy.

Services are considered indirect labor, accounted for as background inputs, and due to the multiplicity of process steps in which labor was applied in the background, it is hardly accountable as hours or years, and therefore is accounted for based on money payments as reflected in price of inputs, multiplied by the emergy cost factor, the Unit Emergy Value of currency (seJ/GDP) in a given year in a given economy.

Although there is no agreement among energy analysts about the way to account for labor and services, the following are the general practices by various groups that we have identified:

(i) in embodied energy analysis, labor is credited as the metabolic energy that is needed to generate it and is only accounted for when no other energy sources are input (i.e. only in subsistence economies);

(ii) some energy analysts use embodied energy (ie fossil energy) values for labor. In this approach, the fossil energy embodied in labor (based on dividing national energy use by the population) is then multiplied by the percent of time the laborer is working (typically 33%, eight hours out of 24)

(iii) in LCA practice, labor is most often not accounted for as an energy input. When accounted for as an input, labor is cumulatively added as working hours, without any quality distinction. However, it does not contribute to the final assessment of impact categories.

(iv) in emergy accounting, labor and services are accounted for as the emergy required to support them. Where data are available labor should be valued based on level of training and education (Odum, 1996). However, since analyses of education and training processes are very uncertain, most of the time labor and services are accounted for as the product of annual wages times, the Unit Emergy Value of currency (seJ/GDP) in a given year in a given economy. It is assumed that generally, wages reflect the training and education levels of different labor inputs.

## 4 L&S accounting procedures in a combined emergy-LCA Framework

Based on the above considerations, accounting for labor and services adds additional important information about the structure, infrastructures and socio-economic development of a society in which a process takes place and how it affects the performance and the cost of the process under investigation.

Money pays for human labor and services. Money never pays for resources. This is often difficult to grasp since we are accustomed to paying for things. While we pay money and receive energy, materials, or goods, the money does not “pay” the oil well, or the environment for food, or the geology for the minerals. The money pays for human service, for digging the well, for plowing the field, for mining the mineral (see Figure 2). If one follows the money through an economy, it clearly appears that it always pays for human labor and service. Thus accounting for the money flows within systems is actually accounting for the quantities of human services associated with material or energy flows. Each input to a process (say for instance fossil fuel inputs to a power plant) has inputs of labor and services, material and energy and each of the inputs of energy and material to that process have inputs of energy, material, labor and services. If one traces back far enough through the web of flows that make up the inputs to a process it is revealed that all the money is used to purchase labor and services. Never, is money paid to the environment or to geology for the materials and energies extracted from them. To the extent that the wages paid by a firm to its employees reflect the level of their actual education and experience, the money multiplied by the emergy money ratio is the emergy value of labor and services. Of course, by means of labor and services, material and energy flows are provided to individual processes, while the emergy resources supporting labor and services are accounted for in the emergy assessment of a country’s economic system.

### 4.1 Simple rules for standardized accounting of L&S

The following are general accounting procedures for including labor and services within a combined emergy/LCA framework:

(i) The emergy value of direct labor (labor as foreground input) should be computed from monetary costs of labor for the process being evaluated and taking into consideration the national economy within which the product or process is located.

(ii) Services associated with material and energy inputs to a process (ie background, indirect labor) are measured by their monetary cost. While this can be assessed for each input item in the supply chain, it is not necessary and can be calculated from the price of final inputs to the foreground. If however, it is desired to have service inputs associated with each of the inputs along a supply chain, then price for each input will have to be generated. The latter will be most difficult and probably best to avoid at least in the short run.

(iii) Money costs of labor and services should be multiplied by the emergy/GDP of the country within which the process/product is located and considering the year of production.

(iv) The UEV of the final product of a process must be calculated with and without labor and services. This is because in a globalized economy while technological processes may not be very different and therefore the UEV without L&S will be relatively similar everywhere, the fraction of emergy cost associated to L&S varies from country to country depending on the monetary cost of labor. Calculating the emergy cost of the final product with and without L&S allows the use of the value without L&S in other evaluations, with smaller risk of errors.

(v) Money costs associated with each input of labor, matter and energy should be calculated in the local currency and multiplied by the local emergy/GDP. Once the calculation is performed, the resulting emergy associated with each flow and the calculated emergy indicators are easily comparable in all countries. It should absolutely be avoided to use money flows in one country, convert them into another country's currency and then use the emergy/GDP of the other country. Values of emergy/GDP are country-specific.

(vi) The combined emergy/LCA methodology could be used to calculate emergy indicators such as Emergy Yield Ratio (EYR), Environmental Loading Ratio (EYR), Percent Renewable (%R) and possibly the Emergy Sustainability Index (ESI). The methods of calculation for products and processes are still being developed as far as the emergy/LCA framework is concerned. We believe that this will require a careful analysis of the framework and adaptation of the static calculation method, which deserves a critical appraisal and a separate concept paper. A combined emergy-LCA framework should include labor as a foreground input to processes and products using the money paid for wages whenever possible. This may require developing wages databases for production processes. The background service input should be evaluated as the money paid for inputs (other than labor) to the foreground using prices of all inputs of materials and energy. If it is not possible to obtain wages for production processes, then the fall back would be to determine human service and labor as a combined input by using the price of the final product produced and multiplying by the Emergy/GDP ratio for the economy within which the process/product is located.

(vii) Renewability of labor and services. Raugei et al (2005) pointed out the importance of keeping track of renewable fractions within the emergy metabolic chain from background to foreground processes: "*When a given item from a process is supplied as an input to another process, its emergy is transferred to the new process, so that the memory of previous processes is not lost. However, what is most often lost is the information embodied in the share of R, N, and F, which characterizes each input flow. On the scale of the new process, the flow is usually accounted for as purchased nonrenewable (F) in the calculation of performance indicators. Thus, locally renewable driving forces seem to lose relevance as the observer moves farther and farther from primary processes. This practice is surprising within the body of a theory based on the "memory" of a product history. We suggest that performance indicators be calculated preserving the characteristics of the inputs (% R, N and F)"*. In line with such rationale, the renewable fraction of L&S may also be accounted for, although it is sometimes negligible. Direct and indirect labor can also be considered, at country level, as the final product of the entire country metabolism. In a like manner, GDP (Gross Domestic Product) can be considered as a co-product of the same process. As a consequence, Labor and Services should be credited a fraction of renewability proportional to the fraction of renewable emergy supporting the country. In practice, if the emergy flows of goods, labor, or services are generated within a process characterized by a given fraction of renewables, these flows should also be considered renewable by the same fraction. In so doing, the contribution of input flows to a process performance is not necessarily non-renewable on the larger scale of the system in which the investigated process is embedded, but offers a variety of intermediate possibilities, with sometimes non-negligible effects on the calculated performance indicators. Accounting for the renewable fraction of Labor and Services does not affect the EYR (sensitive to the local vs imported alternative), but instead largely affects the ELR (sensitive to the renewable vs nonrenewable alternative, no matter where R comes from), ESI and %REN indicators.

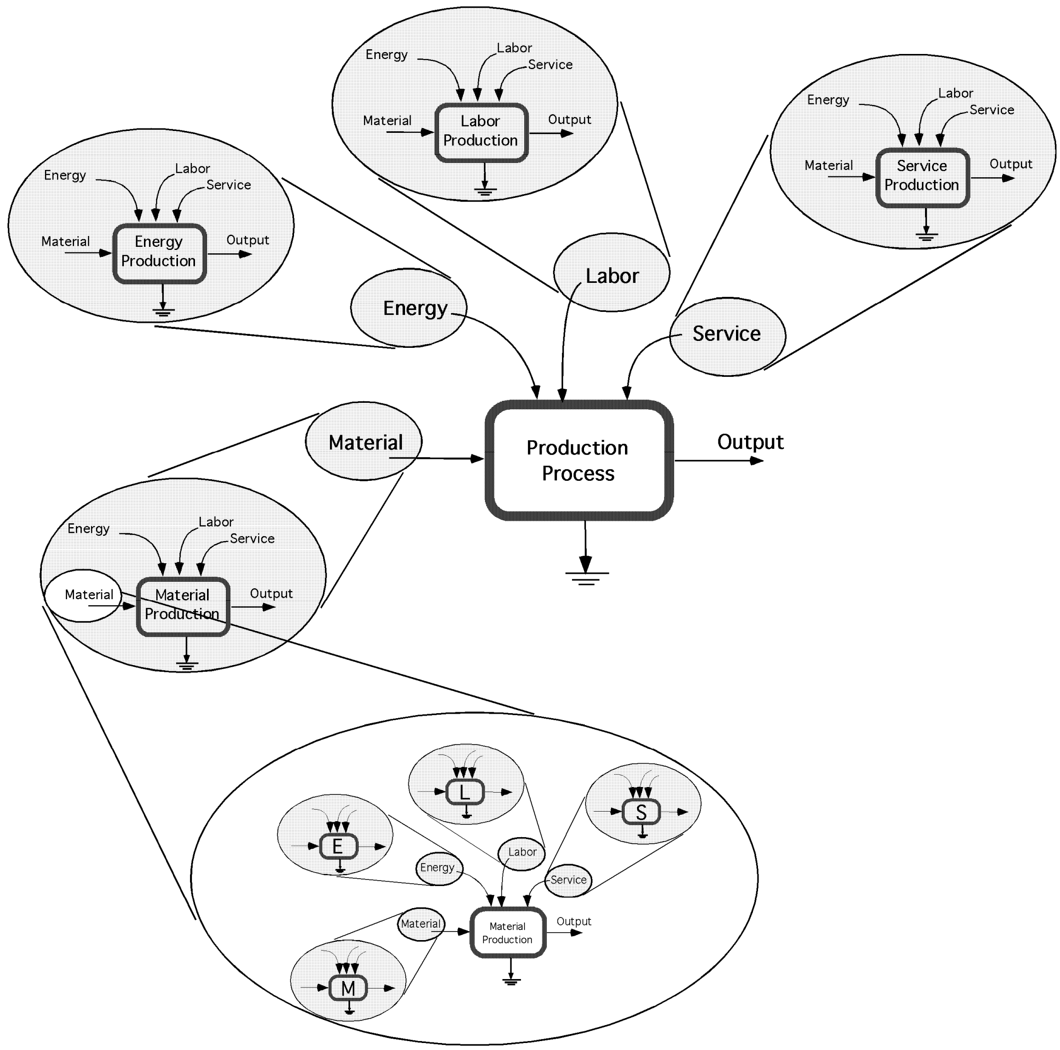


**Fig. 2.** Diagram showing the web of inputs to a process and the fact that each is composed of inputs of energy, materials, labor and services and that ultimately all money paid for a product is used to purchase labor and services.

## 5 Conclusions

Labor and services are an important part of any process taking place in economic systems. Through L&S, the entire dynamics of the larger socio-economic system in which a process is embedded is transferred to the production system and affects its performance, by supplying know-how, information and personal skills, as well as by allowing the use of societal infrastructures. A standardized procedure is needed to account for L&S in emergy assessments, as well as in any other evaluation methods. Disregarding L&S accounting prevents from fully understanding the relations between the system under consideration and the larger surrounding environment. In this paper, procedures for L&S standardization are discussed and use of L&S in an integrated Emergy-LCA framework is suggested.

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