Ecological Indicators 60 (2016) 884–892

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Development of concepts for human labour accounting in Emergy Assessment and other Environmental Sustainability Assessment methods

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ARTICLE INFO

Article history:
Received 31 March 2015
Received in revised form 13 July 2015
Accepted 5 August 2015

Keywords:
Labour
UEV
Emergy
Embodied energy
LCA
Sustainability assessment

ABSTRACT

Human labour is central to the functioning of any human-influenced process. Nevertheless, Environmental Sustainability Assessments (ESAs) do not systematically include human labour as an input. Systematic omission of labour inputs in ESAs may constitute an unfortunate, significant bias in favour of labour intensive processes and a systematic underestimation of environmental impacts has implications for decision-making. A brief review of the evaluation of human labour in ESAs reveals that only Emergy Assessment (EmA) accounts for labour as standard. Focussing on EmA, we find, however, that there is no agreement on the calculation method for labour. We formalise the calculation of human labour unit emergy values (UEVs) as being the ratio between the emergy resource basis of the labour system and a proxy for labour, with or without allocation to account for different qualities of labour. The formalised calculation approach is demonstrated using examples from the literature (USA, with allocation based on educational level; Ghana, with allocation based on income level; the World, with no allocation). We elaborate on how labour may be considered as endogenous or exogenous to the studied system, and how inputs can be categorised as direct labour taking place in the system under study and indirect labour occurring upstream in the supply chain associated with the studied system. With appropriate modifications, the formalised calculation approach and the distinction between direct and indirect labour may be transferred to other ESA methodologies. Concerning EmA, we recommend that product UEVs should systematically be calculated with and without labour, and that working hours rather than salary should be used when accounting for labour inputs. We recognise that there is a risk of double counting of environmental impacts when including labour. We conclude, however, that it can be ignored for most production systems, since only a negligible fraction of emergy already accounted for is likely to be included in the emergy flow from labour inputs.

1. Human labour in Environmental Sustainability Assessments

Potential environmental impacts of human activities are estimated in Environmental Sustainability Assessments (in the following designated ESAs) with the goal of reducing resource use and/or environmental pollution (Moldan et al., 2012; Ulgiati et al., 2011). A multitude of ESA methods and approaches exist, e.g. Life Cycle Assessment (LCA) (EC, 2010), Energy Analysis (Herendeen, 2004), Exergy Analysis (Wall, 1977), Emergy Assessment (Odum, 1996). The methods originate from various scientific branches and emphasise different specific aspects and perspectives. Many apply a life-cycle perspective, indicating that ESA includes activities associated with various life-cycle stages of a product or service. ESAs must also embrace activities in a spatial scope through the selection of those activities that are supposed to be relevant. Such activities are sufficiently associated with the studied system and cause significant impact according to specified cut-off criteria (EC, 2010:102). Thus, a typical ESA systematically includes inputs that are required for the process under study and that, in a life-cycle perspective, are considered to significantly impact the environment.

Usually, ESAs are focused on material and energy inputs (e.g. ISO, 2006:3.21) while labour inputs are considered outside of the scope and therefore not systematically included. All processes of production and provision of services to society, however, involve human intervention, represented by the input of labour. Human labour inputs constitute the process control function without

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http://dx.doi.org/10.1016/j.ecolind.2015.08.011
1470-160X/

which little would happen. With no human control, there is no application of information and there is no organisation of material and energy inputs. Nevertheless, standard ESA inventories rarely include human labour inputs and few attempts have been made to establish relevant data basis, e.g. human labour intensities for Life Cycle Assessment (LCA) software.

The rationale behind including labour inputs is the same as the rationale for including material and energy inputs: when the provisioning of an input has a significant up- or downstream environmental effect, i.e. is 'quantitatively relevant', and that effect is attributable to the system, then that input shall be accounted for (EC, 2010:102). ESAs that do not include labour inputs do not provide the full picture of the system under study. There is a risk that systematic omission of labour inputs in ESA constitutes a leakage of environmental effects linked to human labour necessary for specific processes. This externalisation of environmental impacts is likely to result in miscalculation of the environmental profile of production and service systems, particularly if they are labour intensive considered in a life-cycle perspective. Studies exist where results are shown with and without labour and where it is concluded that labour plays a dominating role (46% of total emergy use in Bonilla et al., 2010; 65–71% of total emergy use in Kamp and Østergård, 2014; 89% of total emergy use in Markussen et al., 2014). As of yet, however, emphasis has not been put on showing whether conclusions change when labour is excluded/included. By raising this hypothesis in the paper, we hope to provide a starting point for further elaboration on this issue. It follows that the interpretation of results based solely on material and energy flows may lead to different conclusions compared to when results are based on material, energy and human labour flows combined. This clearly has implications for decision-making.

By including labour, it is possible to recognise the potential environmental effects of establishing and maintaining information infrastructure (e.g. education, media), living infrastructure (e.g. housing, food), transport infrastructure (e.g. roads, vehicles), administration infrastructure (e.g. state organisation, laws and protection) and other goods and services that are supportive of, and necessary for, human labour availability. Proponents of including labour in ESAs argue that the functioning of specific production systems is unequally dependent on these structures through unequal dependence on labour (Rugani et al., 2012; Kamp and Østergård, 2014; Markussen et al., 2014). Therefore, environmental sustainability should be assessed also through estimates of actual labour requirement and linkages between labour input and different labour provision support structures that, in turn, have up- and downstream environmental effects. The development of methods for including labour in standardised LCA, Energy Analysis, Exergy Analysis and Emergy Assessment (EmA) is ongoing, and briefly outlined here.

LCA is a widely recognised and popular method to quantify "all relevant emissions and resources consumed and the related environmental and health impacts and resource depletion issues that are associated with any goods or services ("products")" (EC, 2010). Attempts have been made to incorporate labour as an input flow similar to other flows in product systems: Nguyen et al. (2007) and Silalertruksa and Gheewala (2009) applied different approaches to estimate the energy intensity of agricultural labour in Thailand measured in MJ/h. Lately, the methodological challenges and opportunities were discussed when Rugani and Benetto (2012) and Arbault et al. (2013) highlighted similarities and discrepancies between emergy and LCA. Among these were how environmental effects of labour inputs could and should be modelled. Further, Rugani et al. (2012) provided detailed estimates of human labour LCIA indicators for 15 EU countries, based on household expenditures.

Energy analysis is a method used to determine the embodied energy required to produce a product or service (IFIAS, 1974) and it can be seen as an indicator of environmental impact (Herendeen, 2004). According to Herendeen (2004), it is not usual to consider human labour in Energy Analysis but many authors do consider labour a valid input (Brown and Herendeen, 1996), often in assessments of different types of agriculture. For instance, Fluck (1992) summarised methods and values for energy content of labour, while Freedman (1982) showed the importance of human labour in a rice production by considering the worker hours and the energy cost per hectare. Cleveland (2013) associated an energy cost to human labour composed by the caloric value of the food consumed by the worker, the embodied energy of that food and the fuel purchased with salary.

Exergy analysis is a measure of the maximum amount of work that a system can perform when it is brought into thermodynamic equilibrium with its environment (Wall, 1977). Sciubba (2001, 2003) proposed a resource-based quantifier method, called "extended exergy accounting" in which both labour and financial services are linked to equivalent resource consumption by quantifying the total exergy consumption to generate one man-hour of work or one monetary unit of currency. Fukuda (2003) affirmed that "labour itself is exergy" and characterised a human being as a thermodynamic system that generates force from food. Accordingly, the exergy of human labour should then be calculated based on exergy from food and on exergy from the inputs to produce food.

Emergy Assessment (EmA) is a thermodynamics-based method centred on the approach of accounting for different forms of energy using different energy quality conversion factors, called Unit Emergy Values (UEVs). Solar emergy is the available solar energy used up directly and indirectly to make a service or product (Odum, 1996) and we refer to the unit as solar equivalent joule, abbreviated seJ.[1] The conversion of inputs, given in physical (J, kg, L, k Wh, etc.) or monetary units to (solar) emergy takes place by multiplication with the respective UEVs. As an example, a UEV for gasoline is 187,000 seJ/J, indicating that the equivalent of 187,000 J of solar energy have been dissipated in the creation, production, refining and transport to gas stations per joule of exergy in gasoline (Brown et al., 2011). EmA is more thoroughly described in Odum (1996). Among ESA methods, EmA stands out because of its systematic inclusion of work provided by nature (e.g. creation of oil) and of its systematic inclusion of human labour, even if the approach for considering the latter, as will be shown in Section 2, is not agreed upon.

This brief review shows that it is not new to consider labour as an input, but also that doing so remains peripheral. We interpret the reason for this to be the lack of a conceptual approach that is compatible across ESA methods. We will elaborate on methodological issues relevant for labour calculations in EmA with the aim of establishing a robust conceptual framework for the evaluation of human labour. Afterwards, this advancement may facilitate the development of routine calculation for the value of human labour in ESA. In Section 2, we illustrate how labour can be considered as either an endogenous flow or an exogenous flow. We summarise the different approaches in EmA for calculating the emergy flow related to human labour, propose a general procedure for assessing labour in emergy evaluations and demonstrate this procedure in three calculation examples. In Section 3, we conceptualise the distinction between direct and indirect labour and we show how emergy of labour can be aggregated across various inputs and supply chain levels. In Section 4, we discuss methodological issues related to

[1] Currently, there is no consensus concerning how to designate the unit. The unit is also referred to as solar emjoule or solar emergy joule and with the abbreviations semj or sej.