Accounting for human labour in LCA: a novel Input-Output approach

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Abstract

One of the most controversial topic in Life Cycle Assessment (LCA) concerns the evaluation of environmental impact of human labour. The omission of human labour effects may constitute an unfortunate bias, resulting in leaking of environmental effects and, thereby, systematically misinformed decision-making. In this paper, the innovative Bioeconomic Input-Output model is proposed to internalize human labour in LCA. Specifically, the production of human labor is defined as a new productive sector of a given economy: this process absorbs a portion of the national final demand in order to produce working hours. Both the standard and the Bioeconomic models are then applied for the analysis of goods and services produced by the Italian economy in 2010, and results are compared. This model aims at representing a step forward in the process of internalization of human labour externality in LCA.

1. Introduction

One of the most controversial topic in Environmental Impact Analysis concerns the environmental burdens caused by human labour (Xu et al., 2009). According to literature, the omission of labour effects may constitute an unfortunate bias, resulting in leaking of environmental effects and, thereby, systematically misinformed decision-making (Kamp et al., 2016).

Both Environmental and Economics disciplines are involved in the debate concerning the treatment of labor as a factor of production (Ayres, 2004). Economists define human labour as an independent primary input with respect to the economic system (Faber and Manstetten, 2009), while ecologists consider itas one product of the society: as the other goods and services, production of human labour is ultimately sustained by consumption of primary resources (and emission of wastes) (Ayres, 2001). As a matter of fact, working hours are produced by workers that, in turn, spend their salaries buying and consuming goods and services required to support their life (e.g. food, clothing, housing, etc.), and causing additional direct and indirect environmental impacts that should be properly taken into account. The inclusion of such effects within the environmental burdens of goods and services is here referred as *human labour internalization*, for which one unique and univocally accepted accounting method has not been established yet (Ayres, 2004; Pokrovskii, 2011).

1.1. Aim of the work

In this paper, the *Bioeconomic Input-Ouput model* is proposed as an innovative method to account for the environmental burdens caused by human labour based on the Input-Output framework. More specifically, a *labour production* *sector* is decoupled from the Monetary Input-Output Table (MIOT) of national economy according to specific hypotheses and assumptions, deriving a Hybrid Input-Output system that allows to internalize the effects of human labour in the environmental burdens of national goods and services.

2. Human Labour Internalization: a brief literature review

Although many theoretical debates can be found in literature focusing on the role of labor in economy and ecology, few Authors faced the issue of labour internalization from a methodological viewpoint (Ayres, 2004), for two reasons:

- The definition of a unit process for working hours production is extremely difficult and subjected to a great arbitrariness (Treloar, 1998; Wilting, 1996);
- Literature states that contribution of working hours to environmental burdens of products is expected to be negligible for many products of modern economic systems (Boustead and Hancock, 1979). However, numerical proof of this statement has not yet provided.

The unique LCA-based method that directly addresses the internalization of environmental impact of human labour is the *Extended Exergy Accounting* (EEA), conceived by *Sciubba* (Sciubba and Ulgiati, 2005; Sciubba, 2001). The objective of EEA is to account for the exergy embodied in products, internalizing also the side effects of externalities (pollutants emissions, capitals circulation and human labour) according to specific models and assumptions. A detailed review of EEA and other exergy-based methods can be found in literature (Liao et al., 2012; Rocco et al., 2014). Beside EEA, some other Authors indirectly tried to analyze the environmental leffects of human labour. *Costanza* have investigated the *energy theory of value* by comparing the embodied energy and the economic price of products out of the US economy, internalizing households through a Closed Input-Output model (Costanza and Costanza, 1980). Some efforts along this line can be found also in *Duchin*'s publications (Duchin and Steenge, 2007). Differently, *Fukuda* have investigated the relation among labour production and primary exergy requirements at global scale (Fukuda, 2003). A recent review and discussion related to human labour internalization in *EMergy analysis* has been made by Kamp et al. (Kamp et al., 2016).

3. The Bioeconomic Input-Output model

3.1. Theoretical background: Input-Output analysis

Input-Output analysis (IOA) is a cost accounting method tipically applied for the analysis of national economies and for the evaluation of environmental burdens of goods and services (Miller and Blair, 2009; Nakamura and Kondo, 2009). According to literature, IOA constitutes the computational structure of LCA (Heijungs and Suh, 2002; Leontief, 1970).

IOA is usually based on *Monetary Input-Output Tables* (MIOTs) of national economies (Hendrickson et al., 2006), which provide a comprehensive picture of the relation among economic sectors and activities, and are defined according to the *System of National Accounts* (SNA) guidelines (Eurostat, 2013). Thus, MIOTs represent a standardized and constantly updated data source for the application of LCA. For the purposes of LCA, boundaries of IOA must encompass the whole temporal and spatial dimensions of the analyze product in a life cycle perspective (Finkbeiner et al., 2006). Since temporal and spatial extensions of supply chains usually lie across one or multiple national economies, multi-regional MIOTs are usually adopted as reference for LCA computation (Wiedmann, 2009).

National economies are conventionally represented as composed by *n* different productive sectors (economic activities) that produce and trade *n* goods and services (measured in monetary units) for endogenous consumption x_{ij} (intermediate products) or for household consumption f_i (final demand, defined as the useful product of the economy), according to relation (1) (notice that bold fonts are used do denote vectors and matrices).

$$\mathrm{x_i} = \sum_{j=1}^{n} \mathrm{x_{ij}} + \mathrm{f_i} \quad \rightarrow \qquad \mathbf{x}(n\times 1) = \mathbf{Z}(n\times n)\mathbf{i} + \mathbf{f}\,(n\times 1) \tag{1}$$

The *Leontief Production Model* (LPM) (2) allows to evaluate the total production **x** required by the analyzed system once a defined final demand vector **f** and the endogenous transactions matrix **Z** are known. Therefore, LPM allows to understand the *direct* and *indirect* (i.e. *embodied*) amount of each *i*th product of the economy required by the *j*th process to produce one unit of its product.

$$\mathbf{x} = \left(\mathbf{I} - \mathbf{Z}\hat{\mathbf{x}}^{-1}\right)^{-1}\mathbf{f} \tag{2}$$

Each sector of the economy may cause a direct environmental impact (i.e. resources consumption or wastes emission) represented by the *Environmental Intervention vector* **R**. Once this vector is known, the environmental burdens embodied in products of each national economic sector can be evaluated through relation (3).

$$\mathbf{e}(n\times 1) = \left[\mathbf{I} - \left(\mathbf{Z}\hat{\mathbf{x}}^{-1}\right)^{\mathrm{T}}\right]^{-1} \cdot \left[\mathbf{R}(1\times n)\hat{\mathbf{x}}^{-1}\right]^{\mathrm{T}} \tag{3}$$

The model defined by relations (2) and (3) allows to quantify the environmental burden of each product of the considered national economy, the type of which depends on the definition of vector **R**: primary energy/exergy, pollutant emissions, water, land, minerals/metals, and so on.

3.2. Bioeconomic model: theoretical definition

With reference to Figure 1, the generic national economy produces goods and services to fulfill the households' activities (final demand). The national economy can be described as a *circular process* (Miller and Blair, 2009): the final demand that sustains *all* the household activities is compensated by an opposite flow of working hours required to sustain the economic production.

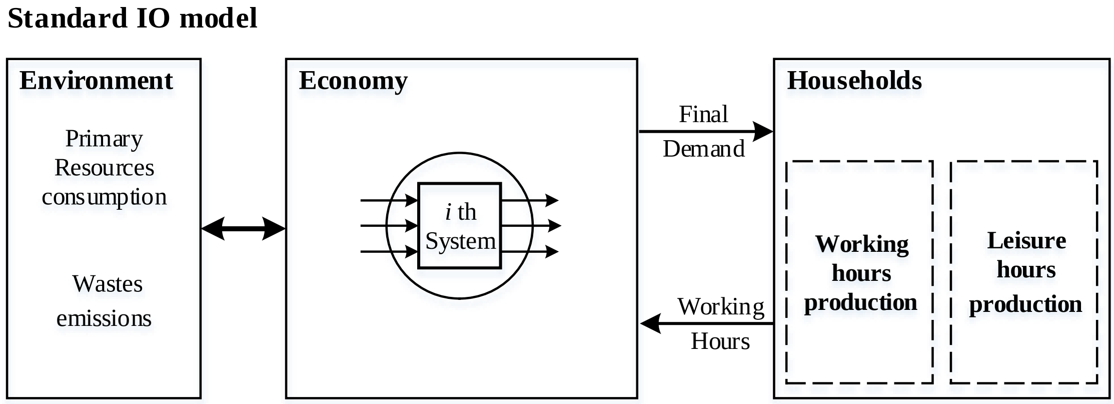

Figure 1: Schematic outline of the standard Input-Output model.

According to the *Neoclassical theory of Labor Supply* (King et al., 1988), the *Bioeconomic Input-Output model* assumes that the total households' final demand is produced with two main purposes: (1) *sustain working hours production*, and (2) *sustain leisure time production*, as can be inferred from relation (4).

$$\mathbf{f}\left(n\times 1\right)=\mathbf{f}_{\mathbf{W}}+\mathbf{f}_{\mathrm{L}} \tag{4}$$

Once a quantitative criterion to share the final demand among these two productive processes has been established, boundaries of traditional IOA can be extended in order to internalize the working hours of production processes as a new sector of the economy, as showed by Figure 2: this new sector (*working hours production*, in the following) receives goods and services from other productive sectors and returns working hours as its unique output.

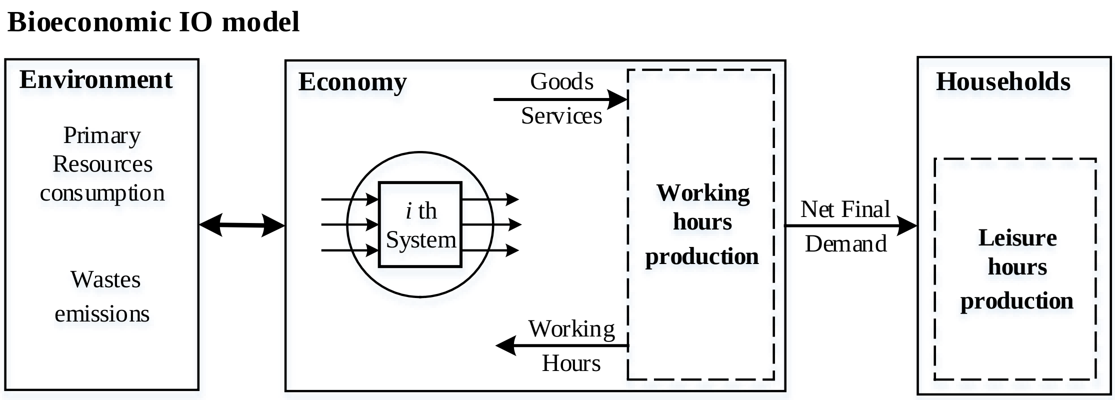

Figure 2: Schematic outline of the Bioeconomic Input-Output model.

To distinguish among final demand **f** used to produce work $\mathbf{f_W}$ and leisure $\mathbf{f_L}$, the *proportionality criterion* is assumed: the amount of goods and services of each sector that feed the production of labour is proportional to the amount of working hours required by the same sector. In other words, the ratio between final demand devoted to sustain working hours production $f_{W,i}$ and total households final demand $f_{H,tot}$ equals the ratio between the amount of hours devoted to working activities $h_{W,i}$ and total hours lived by the entire population h_{tot}, as showed by relation (5).

$$\frac{f_{W,i}}{f_{tot}} = \frac{h_{W,i}}{h_{tot}} \rightarrow f_{W,i} = f_{tot} \cdot \frac{h_{W,i}}{h_{tot}} \rightarrow \mathbf{f_W} = \mathbf{i}(1\times n)\cdot \mathbf{f_H}(n\times 1)\cdot \frac{\mathbf{h_W}(n\times 1)}{h_{tot}} \tag{5}$$

In relation (5), $\mathbf{h_W}$ vector collects the working hours produced by all the *n* economic processes of the economy. According to the proportionality assumption above introduced, the Bioeconomic Input-Output model can be defined as the *partially closed Hybrid Input-Output* model of relation (6).

$$\mathbf{x_B} = \mathbf{Z_B}\mathbf{i} + \mathbf{f_B} \rightarrow \underbrace{\begin{bmatrix} \mathbf{x} \\ h_{W,tot} \end{bmatrix}}_{\mathbf{x_B}} = \underbrace{\begin{bmatrix} \mathbf{Z} & \mathbf{f_W} \\ \mathbf{h_W^T} & - \end{bmatrix} \cdot \mathbf{i}\left[(n+1)\times 1\right]}_{\mathbf{Z_B}} + \underbrace{\begin{bmatrix} \mathbf{f_L} \\ - \end{bmatrix}}_{\mathbf{f_B}} \tag{6}$$

Once the Bioeconomic system has been properly defined by relation (6), the evaluation of specific and total environmental burdens of the net final demand production results again through the application of relations (2) and (3).

4. Case study: analysis of Italian economy in 2010

In this section, the Italian economy in 2010 is analyzed through conventional and Bioeconomic Input-Output models to account for specific and total non-renewable energy-resources embodied in goods and services. The Italian economy is modelled through a MIOT defined by 15 economic activities listed in Table 1. Notice that non-renewable energy-resources are quantified by means of their *exergy equivalents* (International Energy Agency, 2011). All the data required for the application of the methods are retrieved in literature (Timmer et al., 2012). Finally, international trades of products are treated according to the *autonomous region* model (Wiedmann et al., 2011).

Results of the analysis are collected in Table 1 (*specific values*, in kg_{oe}/100€) and Table 2 (*total values*, in ktoe): relative differences ε (in %) between results obtained with the two models are shown for each sector. Based on the obtained results, the following comments can be made:

- The exergy embodied in the total Italian production results equal with both standard and Bioeconomic models (90892 ktoe): this can be established as a check for a correct application of the Bioeconomic model;
- Values of total embodied exergy resulting from the Bioeconomic model change with respect to the standard model: sectors that require less working

hours result in smaller embodied exergy (e.g.*Mining and Quarrying:* -10.9%). The opposite trend holds for tertiary and services sectors (e.g. *Education:* +25.1%);

Table 1: Specific embodied exergy in products of the Italian economy in 2010, in kg_{oe}/100€.

Italian economy, 2010 15 sectors	**ISIC code**	***IO* *e_i***	***B-IO* *e_i***	**ε**
		kg_{oe}/100€	kg_{oe}/100€	**%**
Agriculture, …	AtB	2.04	2.20	**7.5**
Mining and Quarrying	C	203.13	203.15	**0.0**
Manufacturing	D	9.08	9.18	**1.0**
Energy Supply	E	40.54	40.59	**0.1**
Construction	F	4.62	4.74	**2.8**
Wholesale and retail trade …	51	2.62	2.73	**4.1**
Hotels and Restaurants	H	3.17	3.33	**4.9**
Transport, storage, …	I	2.14	2.25	**5.2**
Financial Intermediation	J	0.73	0.81	**11.2**
Real estate, renting, …	K	1.04	1.11	**6.6**
Public Admin and Defence; …	L	1.48	1.62	**10.0**
Education	M	0.59	0.76	**30.5**
Health and Social Work	N	1.76	1.92	**9.0**
Community Services	O	1.90	2.04	**7.6**
Private Households Services	P	0.00	1.40	**100.0**
Working hours production	**W**	**nd**	**6,84**	**nd**

Table 2: Total embodied exergy in products of the Italian economy in 2010, in ktoe.

Italian economy, 2010 15 sectors	**ISIC code**	***IO* *E_i***	***B-IO* *E_i***	**ε**
		ktoe	ktoe	**%**
Agriculture, …	AtB	542	549	**1.3**
Mining and Quarrying	C	1802	1606	**-10.9**
Manufacturing	D	56185	55787	**-0.7**
Energy Supply	E	10262	10147	**-1.1**
Construction	F	6319	6348	**0.5**
Wholesale and retail trade …	51	4427	4477	**1.1**
Hotels and Restaurants	H	2458	2494	**1.4**
Transport, storage, …	I	1985	2011	**1.3**
Financial Intermediation	J	257	276	**7.2**
Real estate, renting, …	K	1830	1903	**4.0**
Public Admin and Defence; …	L	1725	1845	**6.9**
Education	M	396	496	**25.1**
Health and Social Work	N	1848	1955	**5.7**
Community Services	O	853	883	**3.5**
Private Households Services	P	0	114	**100.0**
Working hours production	**W**	**nd**	**0**	**nd**
Total		**90892**	**90892**	

- According to Bioeconomic model, the households' final demand is reduced. Therefore, all the values of specific embodied exergy are higher with respect to the standard model. Again, such increases results greater for products of the tertiary sectors (e.g. Education, Financial Intermediation, etc.);
- Working hours production process is characterized by a value of embodied exergy of 6,84 kg_{oe}/100€. This value can be used as a reference for the embodied exergy in the Italian human labor. However, since working hours are not part of the final demand, total embodied exergy of the working hours production sector is zero: this means that Bioeconomic model results in a reallocation of environmental burdens among all the productive sectors of the economy caused by the internalization of human labour externality.

5. Conclusion

In this paper, the novel Bioeconomic Input-Output method is proposed to include the environmental impact of human labour in Life Cycle Assessment. The method is based on a partially closed Hybrid Input-Output model, and it can be applied to any given national economy in a standardized and reproducible way.

Specific and total embodied energy of Italian economic products in 2010 have been computed according to both standard and Bioeconomic Input-Output models. Results show that the environmental burdens caused by production activities can change significantly if the human labour is taken into account.

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