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LIFE CYCLE THINKING, SOSTENIBILITÀ ED ECONOMIA CIRCOLARE



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

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Fundamental questions:

- Is Human Labour free of environmental impact?
- Is Human Labour conceptually relevant in environmental impact analysis?

Kamp et al. (Ecological Indicators, 2016)

«The typical omission of labour inputs in LCA constitutes an **unfortunate bias** resulting in leaking of environmental effects and **systematically misinformed decision-making**. The hypothesis that environmental assessments which consider labour inputs as “free” from environmental impact will **tend to favor labour - intensive processes** requires additional elaboration.»

Nicholas Georgescu-Roegen (Energy and economic myths, 1975)

«[...] we should cure ourselves of [...] “**the circumdrome of the shaving machine**”, which is to shave oneself faster so as to have more time to work on a machine that shaves faster so as to have more time to work on a machine that shaves still faster, and so on ad infinitum. [...]. We must come to realize that **an important prerequisite for a good life is a substantial amount of leisure spent in an intelligent manner**»

Objectives of this research:

Define and test a **simple** and **reproducible method** to internalize Human Labour in LCA.



Thermodynamics-based approaches

1. **EMergy analysis** (*Odum 1981, 1983, 1996. Campbell 2013, Kamp 2014*)
2. **Extended Exergy Accounting** (*Sciubba E. 1998, 2005, 2014*)
3. **Energy analysis** (*Costanza 1980*)
4. **Cumulative Exergy Consumption** (*Szargut J., 2002*)

Features of the current approaches

- Quantify **average embodied energy/exergy** in Human Labour as ratio between total energy/exergy requirements and total production of working hours of the economy;
- Include Human Labour impact in detailed products without internalize Human Labour production within the economy: **Double Counting error**;

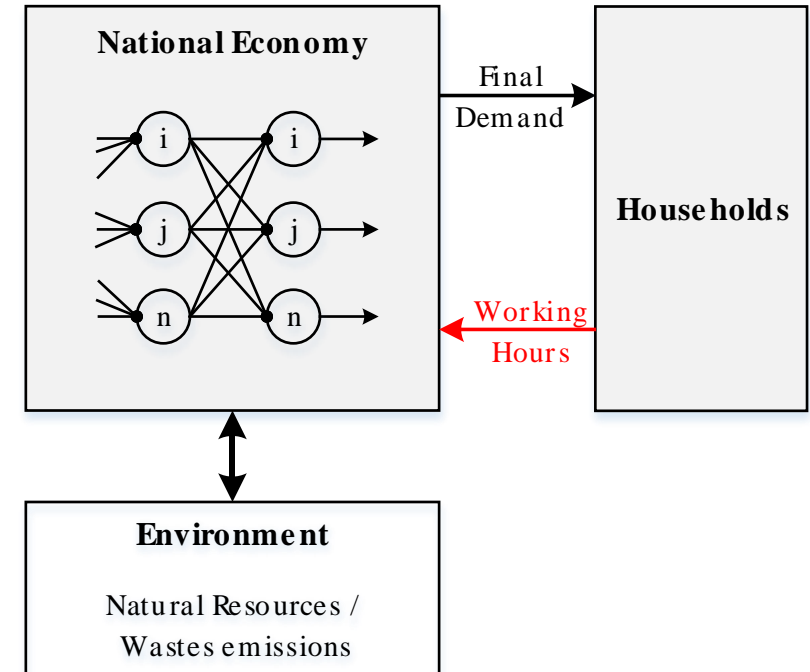
Environmental impact of Human Labour



The environmental impact embodied in goods and services

At global scale:

- Environmental impact is **allocated** on the national final demand (GDP);
- Human Labour is an **exogenous** factor of production: it sustain production of GDP in a **closed loop**;
- Definition of Labour unit process is **difficult** and affected by large **uncertainties**. Moreover, it results in a **double accounting error**.



...a deeper insight in the computational structure of LCA is required!

Input-Output analysis



Derivation of the Leontief model

Let's consider a generic system in a defined time frame:

- Composed by **n processes**;
- Each process produces **1 kind of product**;
- Each process absorbs/releases **m resources/wastes**;

By collecting all the transaction values in **matrix form**:

$\mathbf{x} = \mathbf{Z} \cdot \mathbf{i}(n \times 1) + \mathbf{f}$ Production balance

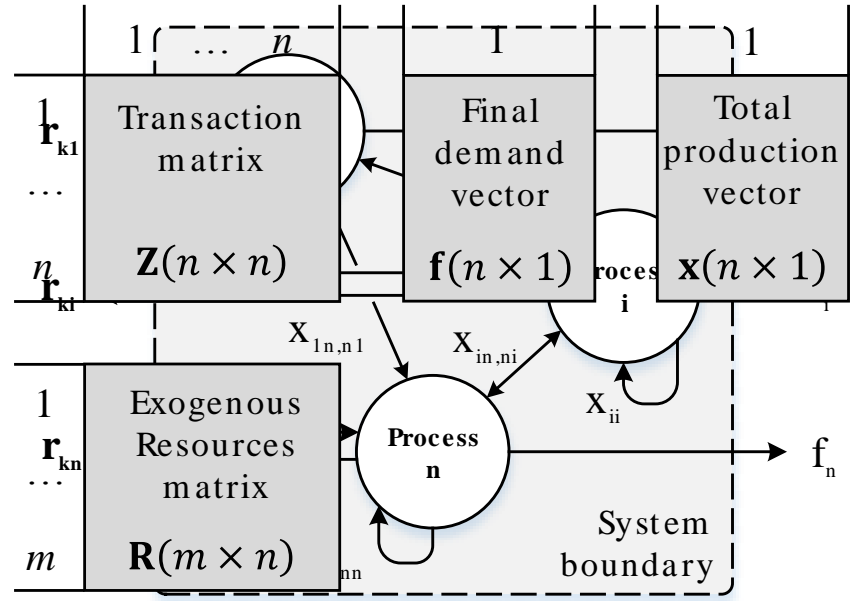
$\mathbf{A}(n \times n) = \mathbf{Z} \cdot \hat{\mathbf{x}}^{-1}$ Technical coefficients matrix

$\mathbf{L}(n \times n) = (\mathbf{I} - \mathbf{A})^{-1}$ Leontief inverse matrix

$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1} \mathbf{f}$ \rightarrow $\mathbf{x} = f(\mathbf{A}, \mathbf{f})$ **Leontief production model**

$\mathbf{B}(m \times n) = \mathbf{R} \cdot \hat{\mathbf{x}}^{-1}$ Input coefficients matrix

$\mathbf{e} = (\mathbf{B}\mathbf{L})^T$ \rightarrow $\mathbf{e} = f(\mathbf{A}, \mathbf{B})$ **Leontief impact model**



- x_{ij} – Endogenous transactions from process i to j
- f_i – Final demand of process i
- r_i – Exogenous transactions of process i

...Environmental impact of detailed products is known if the system is completely characterized.

Input-Output analysis



Computational structure of Input-Output based LCA

Definition and application of the Standard Input-Output model for LCA purposes

1. Production system definition

$$\begin{bmatrix} \mathbf{x}_N \\ \mathbf{x}_S \end{bmatrix} = \begin{bmatrix} \mathbf{Z}_N & \mathbf{C}_{NS} \\ \mathbf{C}_{SN} & \mathbf{Z}_S \end{bmatrix} \cdot \mathbf{i} [(n+1) \times 1] + \begin{bmatrix} \mathbf{f}_N \\ \mathbf{f}_S \end{bmatrix} \rightarrow \mathbf{x}_H = \mathbf{Z}_H \mathbf{i} + \mathbf{f}_H$$

$$\mathbf{R}_H = [\mathbf{R}_N | \mathbf{R}_S]$$

Definition of **production balance** and **Environmental intervention matrix** (coal, oil, natural gas, in terms of exergy)

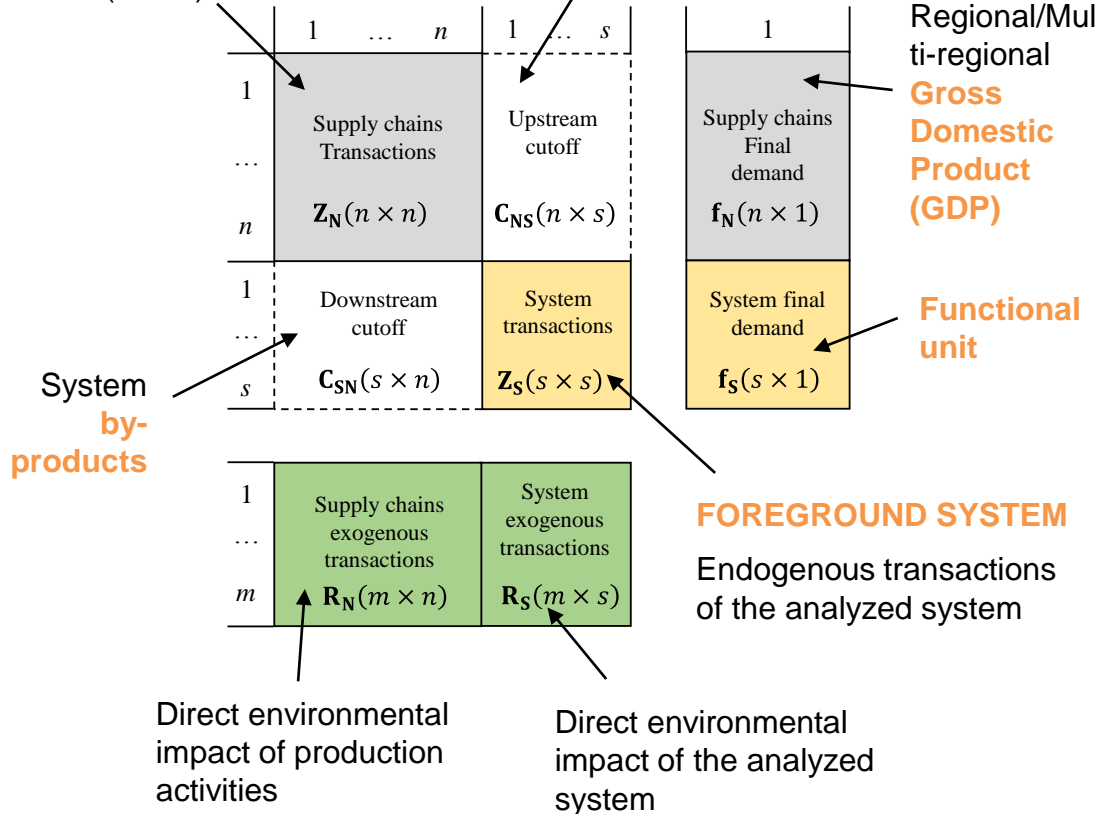
2. Application of the Leontief model

$$\left. \begin{aligned} \mathbf{A}_H &= \mathbf{Z}_H \hat{\mathbf{x}}_H^{-1} \\ \mathbf{B}_H &= \mathbf{R}_H \hat{\mathbf{x}}_H^{-1} \\ \mathbf{L}_H &= (\mathbf{I}_H - \mathbf{A}_H)^{-1} \end{aligned} \right\} \rightarrow \mathbf{e}_H = \begin{bmatrix} \mathbf{e}_{H,N} (n \times m) \\ \mathbf{e}_{H,S} (s \times m) \end{bmatrix} = (\mathbf{B}_H \mathbf{L}_H)^T$$

$$\mathbf{E}_H [(n+1) \times 1] = \hat{\mathbf{f}}_H \mathbf{e}_H$$

BACKGROUND SYSTEM

Regional/Multi-regional Monetary Input-Output Table (MIOT)



Bioeconomic Input-Output model



Internalization of Human Labour in Input-Output analysis

National final demand vector

$$\mathbf{f}_N (n \times 4) = [\mathbf{f}_H \quad \mathbf{f}_I \quad \mathbf{f}_G \quad \mathbf{f}_E] \rightarrow \begin{cases} \mathbf{f}_H & \text{households' purchases} \\ \mathbf{f}_I & \text{purchases for investment purposes} \\ \mathbf{f}_G & \text{government purchases} \\ \mathbf{f}_E & \text{exports} \end{cases}$$

Fundamental hypotheses

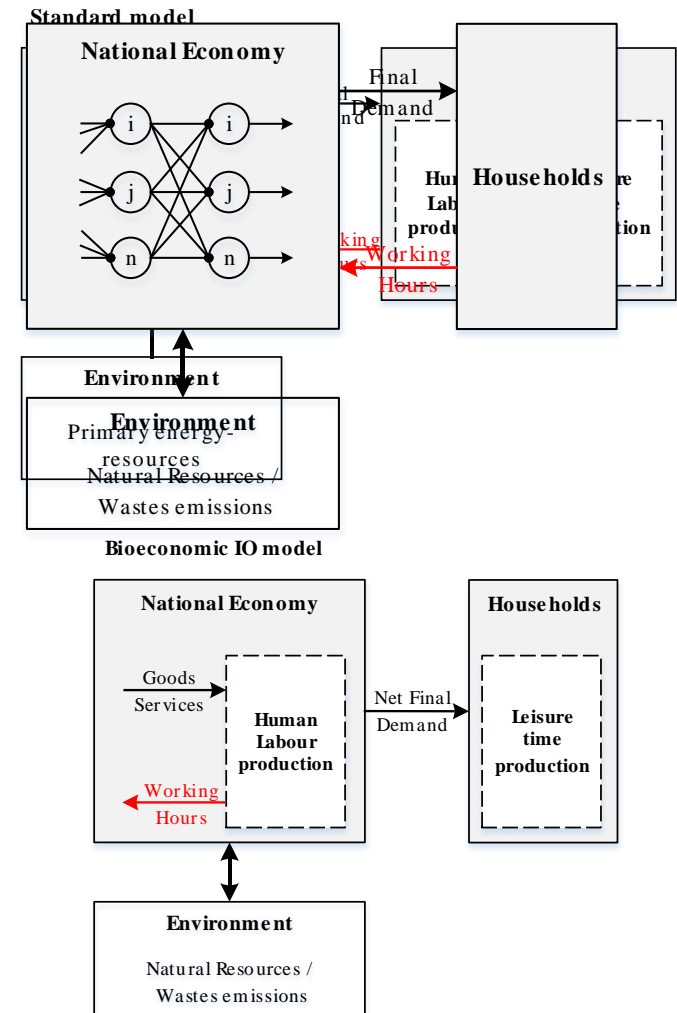
1st hypothesis: national households' final demand can be expressed as the sum of products devoted to sustain **labour** and **leisure**:

$$\mathbf{f}_H (n \times 1) = \mathbf{f}_{H,W} + \mathbf{f}_{H,L}$$

2nd hypothesis: for each i th sector, the products invoked by workers to generate labour is **proportional** to the amount of working hours absorbed by the same sector:

$$\frac{f_{H,W,i}}{f_{H,tot}} = \frac{h_{W,i}}{h_{tot}} \rightarrow \mathbf{f}_{H,W} = \mathbf{i}(1 \times n) \cdot \mathbf{f}_H \cdot \left(\frac{\mathbf{h}_W}{\mathbf{h}_{tot}} \right) \quad (h_{tot} = N_{pop} \cdot 8760 h/y)$$

... the **Human Labour production process** can be defined and internalized within the national economy!



Bioeconomic Input-Output model



Internalization of Human Labour in Input-Output analysis

1. Bioeconomic production system

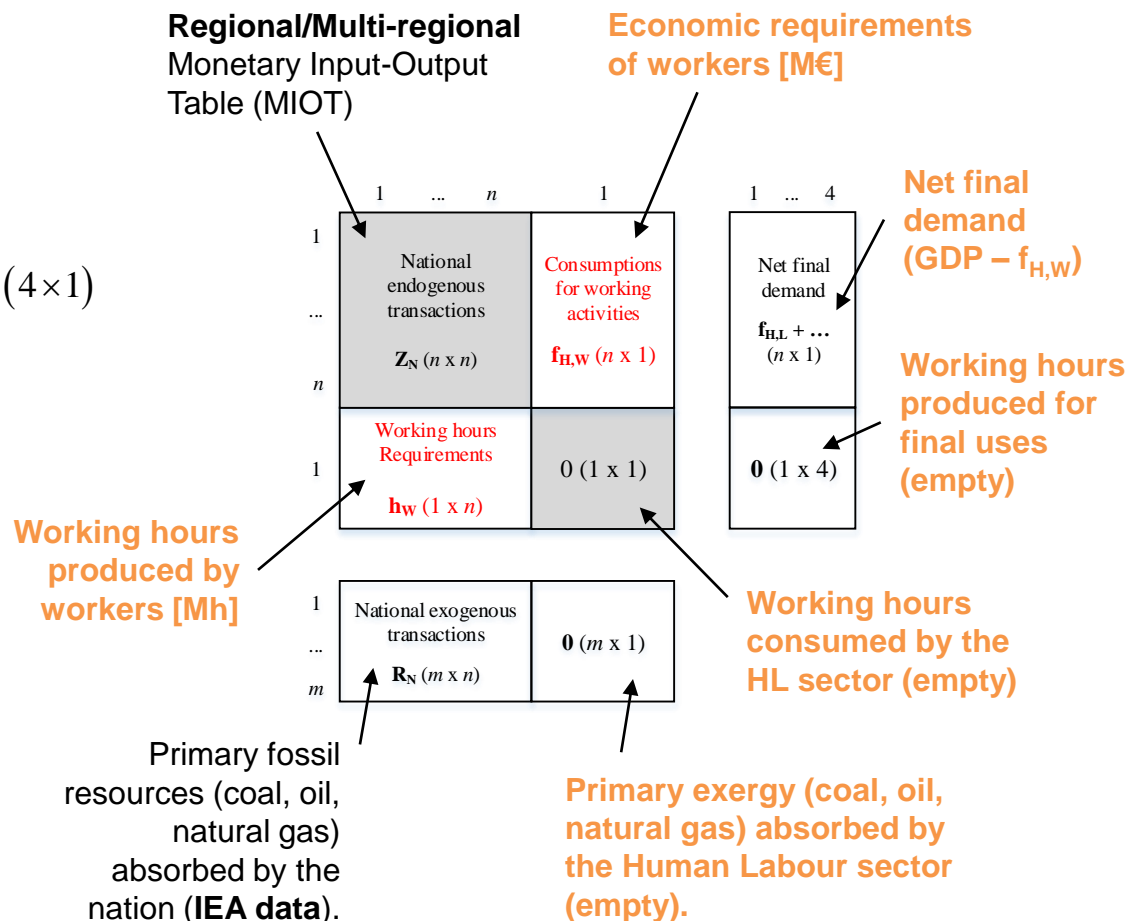
Definition of Bioeconomic **production balance** and **Environmental intervention matrix** (coal, oil, natural gas, in terms of exergy)

$$\begin{bmatrix} \mathbf{x}_N \\ h_{w,tot} \end{bmatrix} = \begin{bmatrix} \mathbf{Z}_N & \mathbf{f}_{H,W} \\ \mathbf{h}_W^T & - \end{bmatrix} \cdot \mathbf{i} [(n+1) \times 1] + \begin{bmatrix} \mathbf{f}_{H,L} + \mathbf{f}_I + \mathbf{f}_G + \mathbf{f}_E \\ - \end{bmatrix} \cdot \mathbf{i} (4 \times 1)$$

$$\mathbf{R}_B = [\mathbf{R}_N | -]$$

2. Application of Leontief model

...

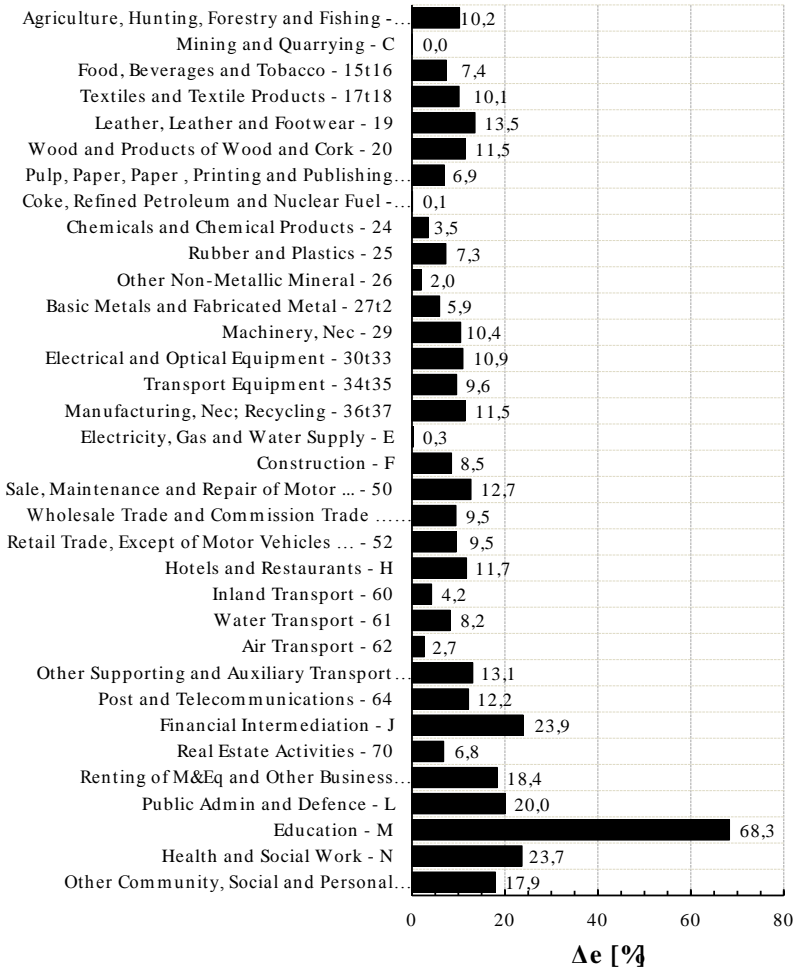


Applications (1/2)

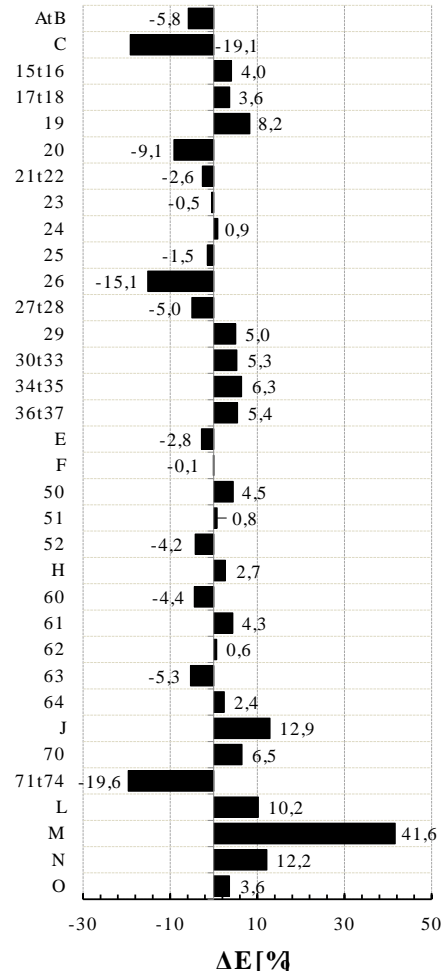


Analysis of the Italian economy in 2010: Bioeconomic VS Standard model

Specific embodied exergy changes



Total embodied exergy changes



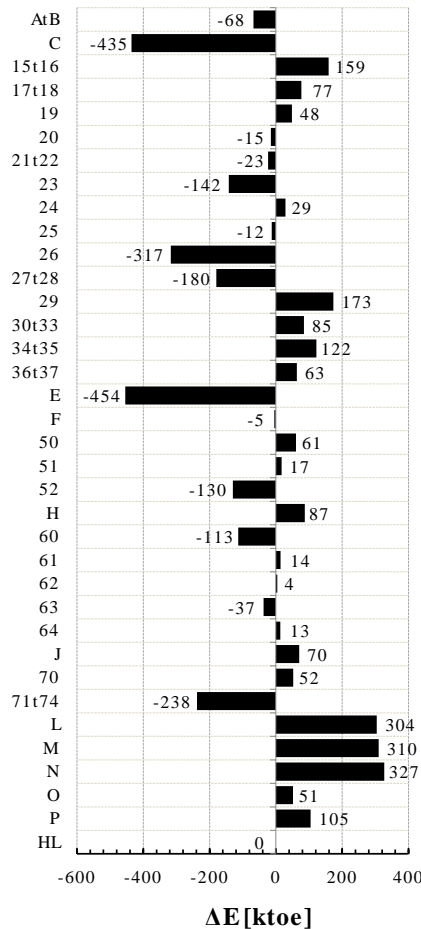
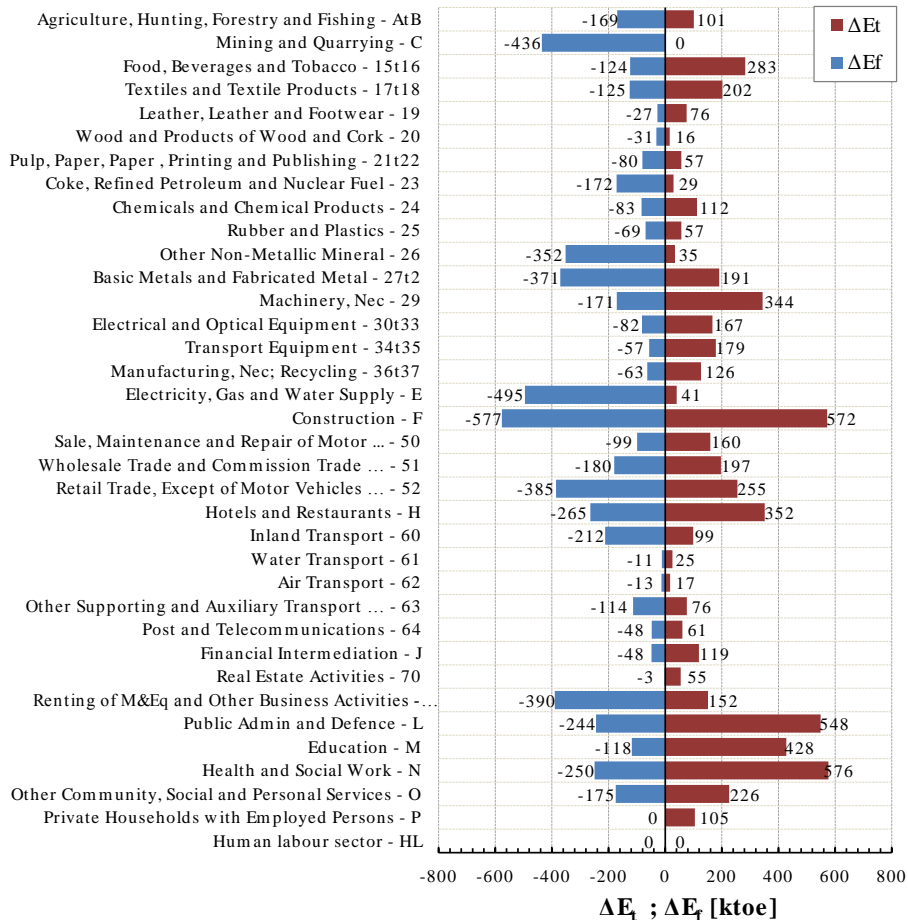
- Specific embodied exergy are **greater**, since the final demand is lower;
 → Environmental impact depends on the definition of the final demand!
- Total embodied exergy may be **lower** or **greater**, but the total embodied exergy consumed by the economy is **constant**;
 → The total impact of a nation is reallocated on the new value of the final demand!
 → No double counting error!
- Human Labour process has a specific embodied exergy of **22 kg_{oe}/100h**, while a total embodied exergy of **0 ktoe**;
 → Human Labour contributes in increasing the embodied exergy of other products, but it is not a product of the economy!

Applications (1/2)



Analysis of the Italian economy: Structural Decomposition Analysis (SDA)

Total embodied exergy changes



Change caused by two overlapped effects:

- Change in technology (qualitative):**
positive contribution given by the internalization of Human Labour sector;
→ More resources are required to produce one unit of product, proportional to its labour requirements;
- Change in the amount of final demand (quantitative):**
negative contribution given by the reduction of the amount of products available for final uses;
→ Less products are available for final uses;

...Human Labour internalization **cause a change** in embodied exergy of products!
...**there is not a direct relation** between working hours consumption and embodied exergy of its production.

Analysis of alternative dishwashing practices: Hand-Washing VS Dishwasher

1. Goal and Scope:

Evaluation of **primary exergy requirements** of the alternatives;
Relying on the **Bioeconomic** and the **Standard Input-Output** approach;

2. Inventory analysis:

Data provided by literature

| Data | Unit | HW | DW |
|-----------------|----------|-----|------|
| Washer | €/unit | 0 | 1000 |
| Water | l/wash | 150 | 15 |
| Electric energy | kWh/wash | - | 1,5 |
| Natural gas | kWh/wash | 3,5 | - |
| Detergents | g/wash | 50 | 30 |
| Human Labour | min/wash | 30 | 10 |

References:

Stamminger R, et al. A European Comparison of cleaning dishes by hand. Proceedings of EEDAL conference 2003. p. 735-43.

Berkholz P, et al. Manual dishwashing habits: an empirical analysis of UK consumers. International Journal of Consumer Studies. 2010;34:235-42.

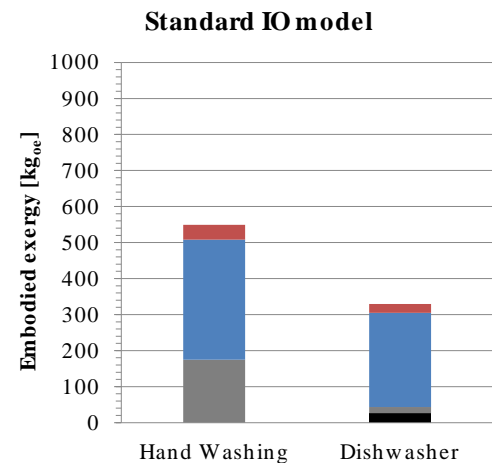
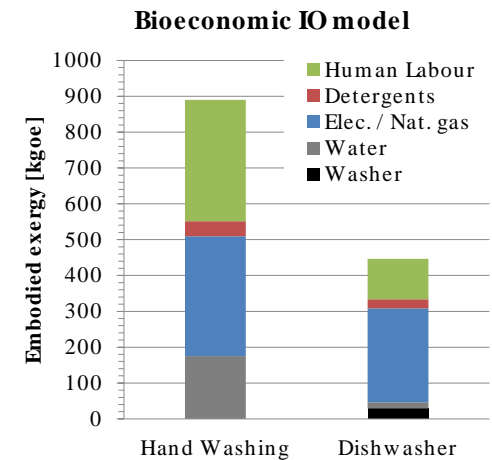
Standard D-D-D. EN 50242. Consumer information related to household electrical appliances. 2008.

3. Impact assessment:

Supply chains models (WIOD database www.wiod.org):

- **Standard model:** Italian MIOT, 2010, 35 productive sectors;
- **Bioeconomic model:** Italian MIOT augmented with Human Labour sector;
- **Primary exergy requirements:** production of Coal, Oil, Natural gas (IEA);

4. Results:





Advantages and Drawbacks of the proposed approach

Advantages:

- It avoids **Double Counting error**;
- It is **simple** and **reproducible**;
- It requires **few** and **largely available** data;

Drawbacks:

- Results are **not comparable** with other classic Input-Output based LCA;
- Only **one average** type of worker is considered.
- The **proportionality assumption** should be further discussed and refined;

«Il vero output del processo economico non è un efflusso fisico di spreco, ma il godimento della vita.»

Nicholas Georgescu–Roegen

Analytical Economics: Issues and Problems, 1966



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Knowledge grows



**SETAC
Italian Branch**

Backup – Numerical results



| Sector name | Code | hw _i Mh | hw _i /h _{tot} % | f _{tot,i} MUSD | f _{H,i} MUSD | f _{H,W,i} MUSD |
|---|------------|-----------------------|--|----------------------------|--------------------------|----------------------------|
| Agriculture, Hunting, Forestry and Fishing - AtB | AtB | 810 | 0,47 | 37202 | 28590 | 5420 |
| Mining and Quarrying - C | C | 57 | 0,03 | 2008 | 350 | 384 |
| Food, Beverages and Tobacco - 15t16 | 15t16 | 578 | 0,33 | 123837 | 94104 | 3868 |
| Textiles and Textile Products - 17t18 | 17t18 | 688 | 0,40 | 77877 | 45825 | 4602 |
| Leather, Leather and Footwear - 19 | 19 | 215 | 0,12 | 30796 | 12925 | 1437 |
| Wood and Products of Wood and Cork - 20 | 20 | 174 | 0,10 | 6294 | 2701 | 1164 |
| Pulp, Paper, Paper, Printing and Publishing - 2 21t22 | 2 21t22 | 334 | 0,19 | 25046 | 16350 | 2235 |
| Coke, Refined Petroleum and Nuclear Fuel - 23 23 | 23 | 40 | 0,02 | 46322 | 25755 | 267 |
| Chemicals and Chemical Products - 24 | 24 | 321 | 0,19 | 84387 | 24550 | 2149 |
| Rubber and Plastics - 25 | 25 | 296 | 0,17 | 24218 | 6905 | 1982 |
| Other Non-Metallic Mineral - 26 | 26 | 363 | 0,21 | 14499 | 3939 | 2430 |
| Basic Metals and Fabricated Metal - 27t28 | 27t28 | 1275 | 0,74 | 82312 | 6826 | 8531 |
| Machinery, Nec - 29 | 29 | 987 | 0,57 | 133806 | 11637 | 6605 |
| Electrical and Optical Equipment - 30t33 | 30t33 | 676 | 0,39 | 88595 | 17661 | 4520 |
| Transport Equipment - 34t35 | 34t35 | 423 | 0,24 | 95678 | 29201 | 2831 |
| Manufacturing, Nec; Recycling - 36t37 | 36t37 | 381 | 0,22 | 47250 | 20790 | 2551 |
| Electricity, Gas and Water Supply - E | E | 191 | 0,11 | 42089 | 40331 | 1276 |
| Construction - F | F | 2173 | 1,26 | 183833 | 10982 | 14539 |
| Sale, Maintenance and Repair of Motor ... - 50 | 50 | 628 | 0,36 | 57540 | 48585 | 4201 |
| Wholesale Trade and Commission Trade ... - 51 | 51 | 1092 | 0,63 | 91969 | 57810 | 7302 |
| Retail Trade, Except of Motor Vehicles ... - 52 | 52 | 1664 | 0,96 | 88741 | 61925 | 11130 |
| Hotels and Restaurants - H | H | 1456 | 0,84 | 119980 | 117753 | 9741 |
| Inland Transport - 60 | 60 | 663 | 0,38 | 53411 | 40466 | 4435 |
| Water Transport - 61 | 61 | 49 | 0,03 | 9165 | 4266 | 326 |
| Air Transport - 62 | 62 | 32 | 0,02 | 10798 | 7052 | 216 |
| Other Supporting and Auxiliary Transport ... - 63 | 63 | 644 | 0,37 | 26513 | 15496 | 4309 |
| Post and Telecommunications - 64 | 64 | 380 | 0,22 | 29302 | 25793 | 2544 |
| Financial Intermediation - J | J | 890 | 0,51 | 67090 | 57829 | 5954 |
| Real Estate Activities - 70 | 70 | 103 | 0,06 | 197077 | 183239 | 691 |
| Renting of M&Eq and Other Business Activities | 71t74 | 3344 | 1,93 | 69676 | 18964 | 22371 |
| Public Admin and Defence - L | L | 2141 | 1,24 | 174880 | 1533 | 14319 |
| Education - M | M | 2322 | 1,34 | 98021 | 14344 | 15532 |
| Health and Social Work - N | N | 2339 | 1,35 | 168185 | 29404 | 15645 |
| Other Community, Social and Personal Services | O | 1287 | 0,74 | 70638 | 53563 | 8608 |
| Private Households with Employed Persons - P | P | 2483 | 1,43 | 20438 | 20438 | 16612 |
| Human labour sector - HL | HL | 0 | 0,00 | 0 | 0 | 0 |
| Total | Tot | 31501 | 18 | 2499472 | 1157882 | 210725 |

| Code | e _B kg _{oe} / 100USD | e _S kg _{oe} / 100USD | Δe % | E _B ktoe | E _S ktoe | ΔE % |
|------------|--|--|----------|------------------------|------------------------|----------|
| AtB | 3,44 | 3,13 | 10,2 | 1095 | 1163 | -5,8 |
| C | 113,47 | 113,45 | 0,0 | 1842 | 2278 | -19,1 |
| 15t16 | 3,43 | 3,19 | 7,4 | 4114 | 3954 | 4,0 |
| 17t18 | 3,00 | 2,72 | 10,1 | 2199 | 2122 | 3,6 |
| 19 | 2,16 | 1,90 | 13,5 | 635 | 586 | 8,2 |
| 20 | 3,00 | 2,69 | 11,5 | 154 | 169 | -9,1 |
| 21t22 | 3,84 | 3,59 | 6,9 | 875 | 899 | -2,6 |
| 23 | 64,33 | 64,27 | 0,1 | 29628 | 29770 | -0,5 |
| 24 | 4,01 | 3,88 | 3,5 | 3302 | 3273 | 0,9 |
| 25 | 3,75 | 3,49 | 7,3 | 834 | 846 | -1,5 |
| 26 | 14,77 | 14,48 | 2,0 | 1783 | 2100 | -15,1 |
| 27t28 | 4,60 | 4,34 | 5,9 | 3396 | 3576 | -5,0 |
| 29 | 2,86 | 2,59 | 10,4 | 3636 | 3463 | 5,0 |
| 30t33 | 2,01 | 1,81 | 10,9 | 1692 | 1607 | 5,3 |
| 34t35 | 2,20 | 2,01 | 9,6 | 2042 | 1920 | 6,3 |
| 36t37 | 2,75 | 2,47 | 11,5 | 1229 | 1166 | 5,4 |
| E | 38,88 | 38,78 | 0,3 | 15867 | 16321 | -2,8 |
| F | 4,30 | 3,97 | 8,5 | 7286 | 7291 | -0,1 |
| 50 | 2,66 | 2,36 | 12,7 | 1419 | 1359 | 4,5 |
| 51 | 2,69 | 2,46 | 9,5 | 2280 | 2263 | 0,8 |
| 52 | 3,79 | 3,46 | 9,5 | 2940 | 3070 | -4,2 |
| H | 3,04 | 2,72 | 11,7 | 3346 | 3259 | 2,7 |
| 60 | 4,98 | 4,78 | 4,2 | 2440 | 2553 | -4,4 |
| 61 | 3,80 | 3,51 | 8,2 | 336 | 322 | 4,3 |
| 62 | 6,21 | 6,05 | 2,7 | 657 | 653 | 0,6 |
| 63 | 2,98 | 2,64 | 13,1 | 662 | 700 | -5,3 |
| 64 | 2,10 | 1,87 | 12,2 | 561 | 548 | 2,4 |
| J | 1,01 | 0,81 | 23,9 | 617 | 546 | 12,9 |
| 70 | 0,44 | 0,41 | 6,8 | 861 | 808 | 6,5 |
| 71t74 | 2,06 | 1,74 | 18,4 | 976 | 1214 | -19,6 |
| L | 2,05 | 1,71 | 20,0 | 3286 | 2982 | 10,2 |
| M | 1,28 | 0,76 | 68,3 | 1055 | 745 | 41,6 |
| N | 1,97 | 1,60 | 23,7 | 3010 | 2683 | 12,2 |
| O | 2,40 | 2,03 | 17,9 | 1487 | 1436 | 3,6 |
| P | 2,74 | 0,00 | 100,0 | 105 | 0 | 100,0 |
| HL | 22,55 | 0,00 | 100,0 | 0 | nd | 100,0 |
| Tot | - | - | - | 107645 | 107645 | - |