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UNEVEN DISTRIBUTION OF BENEFITS AND ENVIRONMENTAL LOAD. THE USE OF ENVIRONMENTAL AND THERMODYNAMIC INDICATORS IN SUPPORT OF FAIR AND SUSTAINABLE TRADE

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ABSTRACT

The paper provides a global framework for the assessment of environmental value, consequences and equity of international resource trade, based on integrated thermodynamic and environmental indicators as a complement of economic evaluation tools. Several methods for material, energy, and environmental assessment are applied in order to ascertain the uneven distribution of economic benefits and environmental loading among countries, as well as the advantage to the buyer and the inequity of trade when it is only based on market value. Resource flows from selected developing countries to Italy are analysed by means of Material Flow Accounting, Land Demand, Energy and Emergy analyses, in addition to their monetary value. Results help highlight and quantify that:

a) the economic growth of developed countries is very often based on the depletion of primary resource storages of developing countries, not adequately compensated in trade dynamics and international agreements in terms of real wealth exchanged;
b) the development of efficient and environmentally friendly technologies in developed countries is sometimes based on "exporting" environmental burden and instability to countries where the primary resources come from.

An innovative allocation method based on matrix algebra is introduced, which allows to split a given environmental impact indicator in portions, which are geographically attributed to the different world regions. This is done on the basis of: (i) where the analyzed process takes place; (ii) where the directly and indirectly required fossil and nuclear fuels come from (including those for electricity production); and (iii) the different emergy/money ratios of the various world regions.

1. INTRODUCTION

It is nothing new that very few wealthy countries have access to and actually use the largest part of the world energy and material resources. The generation of environmental and social instability in several areas of the planet can be discussed in relation to the existence of this disparity. Conventional economic approaches quantify traded flows in terms of the amounts of goods traded and the money paid for them. The economic assessment of trade very often only focuses on money balance and does not take into proper account the real quality of the traded resources as well as the related environmental problems, both from the point of view of the depletion of resources and of the pollution generated in the exporting country. Resources are very often mined and partially processed in the exporting country, then refined and used in the importing developed countries. The price of exported resources is very often inadequate to compensate for the depletion of local storages and the environmental burden that is generated by resource extraction and primary processing. Instead, resources drive significant economic and environmental benefits in technologically and economically developed countries.

The unbalance of resource trade among countries is of paramount importance to environmental and political stability, as clearly pointed out by H.T. Odum [1]: *"Trade and projects that unbalance local economies […] increase emergy inequity between*

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countries, do not maximize the world economy, because they leave major sectors of the world's population in poverty, essentially outside the world economy. This pattern wastes resources into luxury and excess of the developed countries, diverting resources that used to go directly to population support (without payments). This pattern is not sustainable, does not maximize world wealth and emergy, does not reinforce world production, and will not last. These patterns will become discredited as world opinion changes, as revolutions occur, and worldwide resource depletion soon cuts off the largesse of the overdeveloped countries."

Brown (2003) clearly identified the "advantage to the buyer" in the relations between industrialized countries and countries the economies of which are mainly based on exports of primary resources, for a large number of countries worldwide. This happens in spite of an apparent balance of money flows between trading countries. The situation appears even worse when the environmental burden associated to the traded resources is also taken into account and its geographical distribution is carefully investigated.

Sampat [2] provided a vivid picture of the inequity of the present primary resource exchange worldwide, by showing an unequivocal set of data about polluting emissions and trade-offs in mineral extraction and trading. According to Sampat's report, the mining industry was responsible in the late 90's for about 5.3 million square kilometers of threatened forests (39% of the total damaged forest area worldwide), water and air pollution, loss of biodiversity, harm to the people living near the extraction sites, as well as for about 7-10 % of the total world energy use. Based on World Bank data, Sampat also calculated a significant decline (about 40%) in the market price of metals and minerals in the years 1960-2001, which decreased the economic advantage of the exporting countries in spite of the huge environmental problems suffered by them. Finally, analyzing data from UNCTAD [3], World Bank [4] and UNDP-United Nations Development Program [5], Sampat ascertained that several countries with high export of minerals still have large fractions of population below the national poverty line (Table 1), thus confirming the lack of any real economic advantage compensating for the depletion of local resource storage and the related pollution.

Table 1. Share of mineral exports and population below poverty line in selected countries (Sampat, 2003)

Country	Share of Non-Fuel Minerals in Value of Total Exports (%) (%)	Population below National Poverty Line (%) (%)
Guinea	71	40
Niger	67	63
Zambia	66	86
Jamaica	53	34
Chile	43	21
Perù	40	49
Dem. Rep. Of Congo	40	n.a.
Mauritania	40	57
Papua New Guinea	35	n.a.
Togo	30	32

We explore in this paper how selected methods for material, energy, and environmental assessment can be jointly applied in order to assess the fairness of the criteria driving international trade and cooperation agreements between developed and developing countries. We also maintain that environmental and developmental problems cannot be solved by “free market” economy alone. The latter lacks the conceptual framework and the scientific tools needed to deal with the complexity of self-organizing systems, which operate on multiple scales and hierarchical levels.

2. SUSTAINABILITY MULTICRITERIA MULTISCALE ASSESSMENT (SUMMA)

We investigated in the last years several economic and productive systems in which the import-export dynamics play a significant role:

a) *industrial sectors based on technologically advanced materials and devices* (metal ore mining and processing, among which Al, Fe, Cu, Ni, Cr, Li, Ln; MCFC -Molten Carbonate Fuel Cells; advanced photovoltaic technologies, among which CIS-Copper Indium diSelenide and CdTe-Cadmium Telluride thin film modules; hydrogen from several sources, among which steam reforming, water electrolysis, coal gasification).
b) *agricultural sectors* (agriculture, forestry, livestock), and finally
c) *the economy of Italy* as a whole (in different years, with special focus on international trade).

In order to reach more comprehensive results and facilitate their acceptability by the largest possible scientific community, we always perform our evaluations on multiple scales and by means of different approaches (MFA-Material Flow Accounting, Embodied Energy, Exergy and Emergy Synthesis, all within a Life Cycle Assessment framework). To this purpose we developed a new tool (called SUMMA – SUstainability Multicriteria Multiscale Assessment) in which every approach can play its role by answering specific questions on specific scales. The integration is achieved by means of a procedure for the parallel calculation of thermodynamic and environmental performance indicators, specific for each approach. The interested reader can find a detailed discussion of the structure and the added value of the SUMMA framework in Ulgiati et al. [6]; we only list in this paper the main indicators which can be generated by or used within the SUMMA procedure:

1) Local scale optimization (the user can modify and improve the process according to the value of the indicators)

- Energy expenditure (MJ/kg)
- Exergy efficiency
- Airborne, liquid and solid emissions (kg/kg)

2) Global scale framing (the user can compare processes and make choices according to the value of the indicators)

- Material Intensities (hereafter MI; kg/kg)
- Climate change and ecotoxicological impact potentials
- Emergy intensities (seJ/J; seJ/g)The SUMMA method, sometimes in its early developmental stage (i.e. not including all the indicators listed above) has already been successfully applied by the authors to several case studies (Raugei et al. [7]; Bargigli et al. [8]; Raugei et al. [9]; Simoncini et al. [10]; Cherubini et al. [11]). By applying the SUMMA method to agricultural production we provide in this paper a more comprehensive evaluation of such activity and highlight several hidden aspects of trade of agricultural products (so-called “hidden exports” of resources and natural services).

We then focus on trade "fairness" and calculate an emergy-based indicator that attempts to take these hidden exchanges into account as a basis for equitable trade. Finally, we also show that "fairness" of trade and related environmental aspects should be evaluated considering the geographical distribution of input and output flows and allocating benefits and burdens according to the production trajectories of traded commodities; for this purpose, we make use of bauxite production as a simple mineral industry example.

2.1 Focusing on trade

Economists define the so-called "terms of trade", i.e. the relationship between the price received for exports[1] and the amount of imports[2] a country is able to purchase with that money:

$$\text{Terms of Trade} = \frac{\text{Average Price of Exports}}{\text{Average Price of Imports}}$$

The terms of trade are generally equal to 1 for a country, for the obvious reason that it is impossible for any country to purchase commodities from abroad without earning the same amount of money by exporting its own local resources. The terms of trade fluctuate according to changes in export and import prices. Clearly the exchange rate and the rate of inflation can both influence the direction of change in the terms of trade.

Table 2. Terms of Trade of Italy in selected years (Cialani et al., 2004)

	Selected years				
Term of trade	1989	1991	1995	2000	2002
Exports/Imports	0.97	0.97	1.12	1.01	1.03

Table 2 shows the terms of trade for Italy in selected years. When a complete factor price equalization is not observed because of wide differences in resources, barriers to trade, technology, and purchasing power of a country's currency, the result is almost always an increase of the debt for the developing countries. However, since money only pays for the human labour and services, it is highly unlikely that market price take into account the "hidden imports" embodied in the product. In an attempt to take these "hidden imports" into account, traded resources can additionally be characterized by non-monetary indicators, such as those employed in the SUMMA procedure. Some of them, appropriate on a global scale, are:

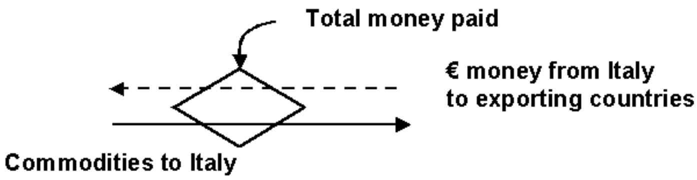
Material Intensity, the overall material input which humans move or extract to make that product or provide that service (Hinterberger and Stiller [12]; Bargigli et al. [13]). The Material Flow Accounting (MFA) method is aimed at evaluating the environmental disturbance associated with the withdrawal or divertion of material flows from their natural ecosystemic pathways. In this method, Material Intensities (MIs) are associated to each input, accounting for the total amount of abiotic matter, water, air and biotic matter that is directly or indirectly required in order to provide the input itself to the analysed system. The resulting total MIs of the system's main output (product) are then calculated as the sum of the MIs of the inputs, and are proposed as cumulative

[1] **Exports:** The sale of *goods, services and energy* to buyers from other countries leading to an inflow of currency to a country.

[2] **Imports:** The purchase of *goods, services and energy* from abroad that leads to an outflow of currency from a country

indicators of upstream environmental disturbance. More on Material Intensities can be found in www.wupperinst.de.

Emergy, a measure of the global environmental support to a system, expressed in unit of equivalent solar energy (Odum [14]; Brown and Ulgiati [15]). The Emergy Synthesis method looks at the environmental performance of the system on the global scale, also taking into account all the free environmental inputs such as sunlight, wind, rain, as well as the indirect environmental support embodied in human labour and services, which are not usually included in traditional embodied energy analyses. In order to identify each flow correctly, we preliminary perform a thorough exergy analysis on the local scale of the system as a necessary pre-requisite for the emergy synthesis. Then, the accounting is extended back in time to include the environmental work needed for resource formation. All inputs are accounted for in terms of their solar emergy, defined as the total amount of solar available energy (exergy) that was directly or indirectly required to make a given product or to support a given flow, and measured in solar equivalent Joules (seJ). The amount of input emergy required per unit of output is called Specific Emergy (seJ/unit) or Transformity (seJ/J), and is used as an indicator of the intensity of the support provided by the biosphere to the product under study (sometimes referred to as "donor-side quality" of the product). The interested reader may refer to www.emergysystems.org. In particular, within Emergy Synthesis, an alternative definition of emergy-based "terms of trade" can be provided, whereby the emergy associated to the traded resource is compared to the emergy associated to the money received. (Figure 1)



$$\text{Emergy benefit to buyer} = \frac{\text{Emergy of traded products}}{\text{Emergy of money paid}}$$

Figure 1. Definition of trade in emergy terms (Odum, 1996)

In this procedure, each traded product is multiplied by a suitable emergy intensity (Transformity, seJ/J, or specific emergy, seJ/g), so that the emergy supporting its manufacture is calculated. The total emergy (embodied resources) associated to the traded product flow is then compared to the total emergy associated to the commodities which can be purchased on the international market thanks to the money received. The difference between the economic and emergy-based "terms of trade" accounting procedures is discussed in detail elsewhere by two of the authors of the present paper (Ulgiati and Cialani [16]), with examples referred to trade between Italy, Denmark and Latvia (Figure 2).

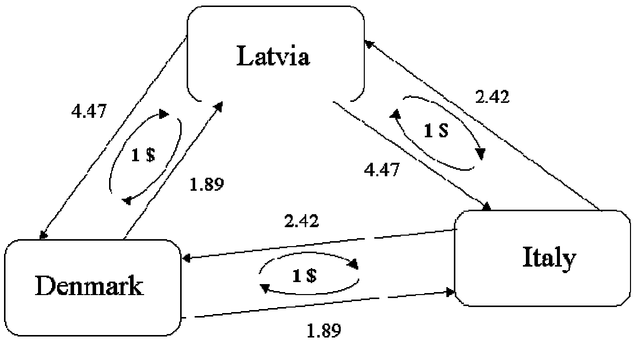


Figure 2. Emergy (x 10^{12} seJ) traded on the basis of 1 $ paid. One $ paid to Latvia buys on the average 4.47 x 10^{12} seJ, while one $ to Italy buys only 2.42 x 10^{12} seJ. Therefore, even if the economic terms of trade are balanced, the actual trade of resources is uneven (advantage 1.85:1 for Italy). Denmark gains from both Italy and Latvia (respectively 1.28:1 versus Italy and 2.37:1 versus Latvia), while Latvia loses in both trade relationships

3. THE CASE OF AGRICULTURE: PRODUCTION AND TRADE

Among the main input flows of energy, matter and labour supporting a generic agricultural process, some flows are locally renewable; others are non-renewable or imported from outside the system (Figure 3). Each flow is characterized by a different quality, both from the point of view of the environment (i.e., how much environmental work supports the flow) and from the point of view of the user (i.e., what the user can extract out of each flow or product).

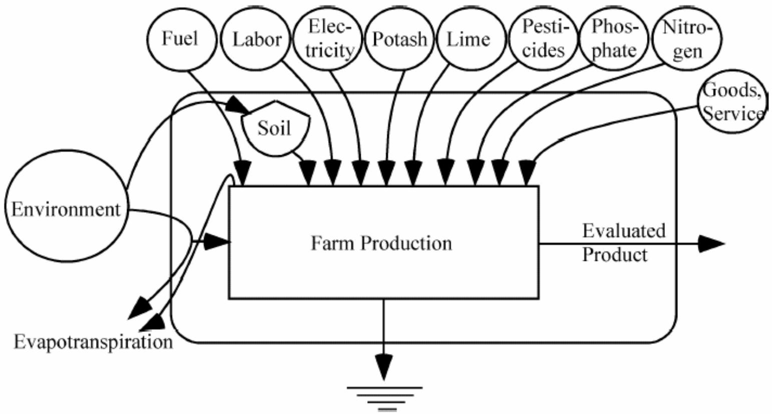


Figure 3. Energy systems diagram of a generic agricultural production process

These flow characteristics cannot be properly accounted for by their money cost, which only measures the cost of the applied human labour and of the willingness to pay for a given product. According to the SUMMA framework, each traded product requires or involves land, water, chemicals, labour, fuels, electricity, and soil erosion, which can be thought of as "embodied" in the product itself. When the product is exported, the embodied flows are also virtually exported. As an example, we calculated non-monetary unit indicators for selected agricultural products of Brazil, Argentina and Chile (Table 3).

Table 3. Non-monetary indicators of agricultural products of Latin-American countries. (*)

Product	Yield (kg/ha)	Land (m^2/kg)	Water (incl.rainfall) (kg/kg)	Chemicals (kg/kg)	Labour (hrs/kg)	Fuels & electricity (kg oil equiv/kg)	Topsoil erosion (g/m^2/yr)	Emergy intensity (seJ/unit of yield)
COUNTRY								
BRAZIL								
Coffee	1150	8.7	8430	0.28	1.11	n.a	1500	1.34E13
Soybean	2600	3.85	4680	0.31	0.005	0.36	1300	1.72E12
Sugar	7340-13300	0.75-1.37	1948-2725	0.05	0.04	0.07	700-7600	6.33E11-1.14E12
ARGENTINA								
Cow meat	250	40	32100	n.a.	0.192	n.a.	895	1.38E14
Pears	28000	0.36	153.6	0.01	0.015	0.06	200	5.87E11
Wood	1600	6.25	3931	0.06	0.001	0.08	200	1.21E12
CHILE								
Peaches	24300	0.41	176.9	0.01	0.021	0.04	200	7.24E11
Apples	32000	0.31	134.4	0.02	0.014	0.05	200	5.43E11

* Source of data: average estimates from different Authors (Stephens, 1984; Pimentel and Krummel, 1987; Biondi et al., 1989; Ulgiati et al., 1994; Ellington et al., 1994; Pimentel et al., 1995; Ulgiati et al., 1997; Guillen Trujillo, 2001; Brandt-Williams, 2002; Rotolo, 2005).

Their values provide a rough estimate of performance of the production process of these agricultural products in developing countries. If the unit values from Table 3 are then used to evaluate the total export from one of these countries to Italy, it is possible to identify a "hidden export" of "embodied" land, water, chemicals, labour, fuels, electricity, and soil, diverted or degraded in order to make the products.

Table 4. Hidden imports of environmental flows, associated to Italian imports of selected agricultural products from all over the world (*)

Product	Amount (10^5 kg/yr)	Land (ha/yr)	Water (10^6 kg/yr)	Chem. (10^3 kg/yr)	Labour (hrs/yr)	Fuels & Electr. (TOE/yr)	Topsoil erosion (10^6 g/yr)	Emergy (seJ/yr)
Coffee	3 620	3.15E+05	6.77E+12	1.01E+08	4.02E+08	n.a.	4.72E+08	4.85E+21
Soybean	12 9000	4.96E+05	6.04E+12	4.00E+08	6.45E+06	4.64E+08	6.45E+08	2.22E+21
Sugar	8 410	8.41E+04	1.93E+12	4.21E+07	3.36E+07	5.89E+07	2.52E+08	8.24E+20
Cow meat	951	3.80E+05	3.05E+12	n.a.	1.83E+07	n.a.	3.40E+08	1.31E+22
Pears	1 160	4.14E+03	1.78E+10	1.16E+06	1.74E+06	6.96E+06	8.29E+05	6.81E+19
Wood	438	2.74E+04	1.72E+11	2.63E+06	4.38E+04	3.50E+06	5.48E+06	5.30E+19
Peaches	6.6	2.70E+01	1.16E+08	6.57E+03	1.38E+04	2.63E+04	5.41E+03	4.76E+17
Apples	542	1.69E+03	7.28E+09	1.08E+06	7.59E+05	2.71E+06	3.39E+05	2.94E+19
Totals		**1.31E+06**	**1.80E+13**	**5.48E+08**	**4.63E+08**	**5.36E+08**	**1.72E+09**	**2.12E+22**

* Source of data for amounts imported: INEA, 2002. Totals are calculated by means of unit factors from Table 3.

Table 4 shows such virtual flows of embodied land, water, chemicals, labour, fuels, electricity, and soil from all world countries which supply selected products to Italy, calculated by means of average values of the unit factors of performance. For instance, the embodied land demand for these imports amounts to a quantity equal to about 24% of the total arable land in Italy. Similarly, water demand equals about 16% of the total water supporting Italian agriculture; topsoil used up due to erosion equals about 26% of the total eroded soil in Italy; chemicals spread on crops equal about 37% of the total amount thereof used in Italy, and so forth. Most products in Table 4 are imported from developing countries, and therefore these "hidden" flows of embodied land, etc. can be thought of as coming from those countries as well.

In a similar way we calculated the emergy associated to the Italian imports listed in Table 3, for the year 2002. The specific emergy of each commodity traded in the year 2002 was multiplied by the raw amount, thus yielding the total emergy imported. Then, the money paid for the imported commodity was multiplied by the emergy/GDP ratio of Italy in the same year, thus yielding in first approximation the emergy associated to the money flow to the country from which commodities come from. Finally the two emergy flows are compared. For example, we obtained emergy exchange ratios 7:1 for coffee from Brazil, 3:1 for wood from Argentina, 13:1 for oil from Venezuela, 41:1 for copper from Chile, among others. Some commodities (pears, peaches, etc) in Table 3 show emergy exchange ratios lower than one, indicating that more emergy goes to the primary producer than to the buyer. This somewhat unexpected behaviour can probably be explained by considering that only a small fraction (very often less than 20%) of the money paid for the goods is actually received by the exporting country, while the remaining amount usually goes to international trade companies. This fact is even more relevant for those commodities (pears, peaches, apples) which are quickly degradable and for which the primary producer has very small margins for market price negotiation, also depending on farm size, local transport, etc. As a further example, Italy imports Fuji apples from the Shandong region of China (La Repubblica [17]). These apples are mainly produced by small farmers, by means of a very labour-intensive production process. The lack of mechanization decreases the energy costs, but a large use of chemical pesticides is needed in order to maximize the yield by preventing losses of product. Small farmers concentrate their products to Shangai and DongYing at a price of less than 0.15-0.17 €/kg. Then, big export dealers (e.g.: the Brilliant Century Agriculture Developing Company, the largest Chinese apple exporting company) take care of sending these apples to Italy by sea. The transport inside China and the shipping to Italy accounts for additional 0.12-0.25 €/kg. Apples are delivered to the port of Ravenna, Central Italy, distributed to intermediate dealers at about 0.45-0.85 €/kg and finally to local markets in the price range 1-2 €/kg. This means that less than 10% of the money paid for the apples goes to the primary producer, while most of it benefits national and international dealers. The emergy exchange ratio should therefore be calculated over the different steps of the trade chain, taking into account the intermediate price and emergy used in each point. Unfortunately data are hardly available to perform this task in full detail. This is quite a general problem, which points to the complexity of today's international market, and would require a thorough in-depth economic analysis of the whole complex web of direct and indirect money flows that take place between many different countries each time that a commodity or good is exchanged. In fact, a simple emergy exchange analysis like the one presented above, although already useful to highlight the need for alternative measures of trade equity, is still unable to provide reliable numerical results in lack of such a previous comprehensive economic analysis.

As a preliminary indication of trade (in)equity, we applied the simple emergy exchange analysis discussed above to the total emergy associated to the same kind of commodities of Table 3 when imports from all over the world are considered (Table 4). The amount of emergy associated to the commodities was calculated to be roughly 34 times as high as the emergy associated to the money paid for them, on the macroeconomic scale. This points to the fact that the trade is unbalanced and that the exporting countries actually support the economic growth of Italy (and of some multinational trading companies), at the expenses of the depletion of their natural resource storages.

The same phenomenon can be detected in many trade relations between industrialized countries and developing countries. In general, one unit of currency ($, €, etc.) buys more environmental resources in a developing country due to the higher emergy/GDP ratio of the latter (Brown [18]), while in turn the developing country buys a very small amount of emergy when buying from an industrialized country (lower emergy/GDP ratio, due to higher monetary circulation). Specific intensities (i.e., performance values calculated per unit of output or per functional unit: soil eroded per kg of product; labour investment per kg; fertilizers per kg; emissions per kg; etc.) provide much more information about a process efficiency than just the money paid for of the product, and could therefore even be used for process optimization or at least improvement.

Money (information about the human labour involved, the buying power of the currency and the willingness to pay) is undoubtedly important in trade assessment but it should be complemented by global "ecological footprint" considerations, i.e. by an evaluation of and a comparison between the environmental supports hidden behind the exchanged flows. This could be achieved by means of emergy synthesis (provided that it is performed following a thorough economic analysis, as explained above), under the assumption that an equitable trade should in principle show an emergy exchange ratio (EER = $emergy_{out}/emergy_{in}$) equal to 1. By highlighting such global-scale (in)equity of resource trade, we do not suggest adjusting local or international market prices of the traded commodities according to emergy-based indicators. However, this certainly requires the adoption of some form of compensation policy between trading countries in order to prevent unfair exploitation of one country's resources. In the following section we will go into more detail of how we envisage that an analysis of environmental performance on the global scale should be carried out, taking into proper consideration all the connections and exchanges taking place between different world regions. Such a "geographic allocation" of environmental impact and resource depletion is in fact, in our opinion, a necessary pre-requisite in order to deal with the complex issue of assessing the equity of international trade.

4. GEOGRAPHIC ALLOCATION OF ENVIRONMENTAL IMPACT

Knowing the absolute or relative value of a performance indicator (e.g., the energy cost per kg of product) does not yet provide all the needed information about the hidden costs of a process or product.

Table 5. Glyphosate imports to Argentina in 2000, from selected countries (Pengue, 2004)

Importing Company	Amount (Kg)	Source Country
Monsanto	9 781 886	EU / Canada
Atanor	2 920 800	China / Australia
Dow	2 186 249	EU
Nidera	1 620 000	China
Queaca	672 000	EU
Zeneca	587 487	China
Icona	168 000	China / Australia
Tex Argentina	126 000	Australia
Cuenca Sur	100 000	China
Nelson Porfin	100 000	China
ACA	90 000	China
Formulagro	83 000	Australia
La Plata Cer.	81 000	Australia
Lab. Nova	80 000	China
Reposo	82 000	EU / China
E. Markmann	71 950	China
Gleba	60 000	China
Cia. Arg. Semillas	40 000	China
Sembrado	20 000	China
UAP	20 000	China
Vestrade	20 000	India
TOTAL	**18 910 372**	

In fact, as already pointed out above, resources are extracted or produced in a given area (oil in Venezuela, copper in Chile, sugar in Brazil, etc.) and then exported somewhere else, where they are further processed and used in the form of manufactured, higher–added-value products. The environmental burden or depletion associated to each traded resource must therefore be allocated to each country involved in each step of the production chain: e.g. oil is extracted and partially refined in Venezuela and burned in the importing country (where the combustion products are generated); sugar is produced in Brazil (with large soil erosion) and safely used somewhere else; advanced technology is widely used in developed countries, but strategic minerals (lanthanides, chromium, lithium, cobalt, etc.) are concentrated in a much smaller number of industrialized and non-industrialized countries.

Table 5 shows the imports of glyphosate to Argentina for agricultural use, in the year 2000 (Pengue [19]). The Table also shows the actual countries from where this chemical was imported. In a global economy nothing is really local, but everything at least partially depends on imported flows. It clearly appears that the environmental burden must be allocated to both the producing and the importing country (the pesticide is used in Argentina, but produced somewhere else), also taking into account possible allocation to other countries from which the intermediate products or the fuels come from. We will show in the next Section how such an allocation can be performed.

4.1. Allocation Method

In order to give a clear picture of the allocation method, we decided to focus on selected primary mining activities. In fact, these are interesting case studies for the application of our method of analysis since they can be regarded as the foundations of the international exchange of goods and commodities. Moving from the widely accepted methods of Material Flow Accounting and Emergy Accounting, our research group is currently developing a computational procedure whereby the main environmental impact indicators of these methods (respectively Material Intensity Factors and Transformity or Specific Emergy) can be geographically allocated to the different world regions where the mineral production takes place.

The procedure also takes into account the contribution to the aforementioned impact indicators caused by the exchange of fuels, both those employed directly and those required for electricity production. For our purpose the world was divided into nine regions of comparatively homogeneous characteristics, namely: OECD Europe, OECD America, OECD Pacific, Middle East, Asia excluding China, China, Latin America, CIS (former USSR), and Africa (Figure 4).

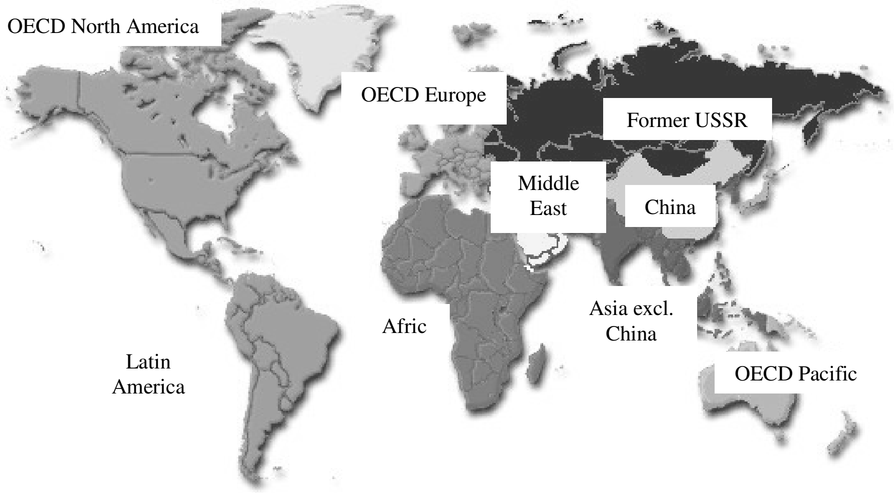


Figure 4. Division of World into 9 homogeneous areas

The method, which is based on matrix algebra, looks at one metric ton of specified mineral sold on the international market, and it tracks the percentage of world production taking place in each areas. In particular, the procedure develops as follows (see also Figure 5):

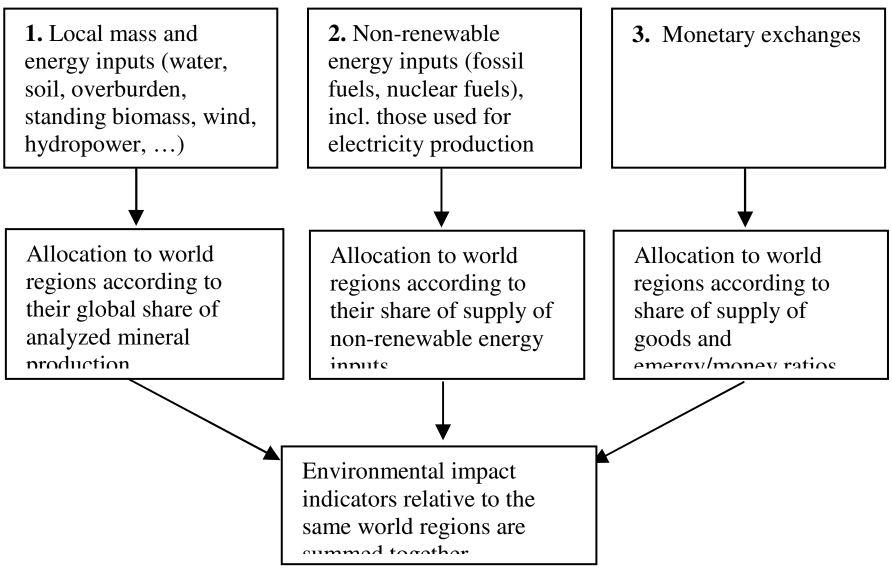


Figure 5. Flowchart of allocation procedure

1) The contribution to impact indicators caused by locally exploited inputs (e.g. water, soil, overburden, etc.) are totally allocated to the mineral producers according to the world mineral production percentages. All local emissions are also regionalised this way.
2) The following steps take into account the fossil fuel and nuclear fuel requirements for the mineral production, both as direct inputs and for the production of the electricity needed for the extraction and processing of the mineral. The contribution to the impact indicators caused by these fuel flows are attributed to the fuel producing regions, on the basis of the geographic distribution of the total world production for each fuel, in order to provide a reference framework which can be representative of the international market.
3) The last step consists of the regionalization of the emergy associated with the monetary exchanges. It is important to note that these monetary exchanges occur not only when the mineral is eventually sold on the international market, but also, previously, when the necessary fuels for the extraction and processing of the mineral are purchased from the fossil fuel producing regions. The contribution to the specific emergy of the mineral caused by the monetary exchanges is evaluated making use of the averaged emergy/money ratios of the producing regions. Last but not least, as we already said in section 3, the emergy flows associated to all monetary exchanges (services) should always closely mirror the way in which the monetary exchanges themselves are organised and subdivided in the complex web of today's international market.

The final result is the complete regionalization of the material intensity factors and of the specific emergy of the specified mineral, whereby the analyst can see which are the world regions that are more heavily impacted in terms of depletion of material resources (MFA method) and in terms of requirement for environmental support (Emergy method).

This innovative approach extracts new information from aggregated indicators which are usually only calculated on the global scale, and is able to correctly take into account the complex web of international links which lie behind all industrial activities. In principle, it can be applied to every kind of indicators, although some of them are global-scale by definition (e.g.: CO_2 emissions), in the sense that their effects are not limited to a specific site or nation, but spread immediately to the whole planet.

4.2. Case study: bauxite mining and processing

Bauxite extraction and processing was selected as a first preliminary case study for this new regionalization procedure. Bauxite is formed by the natural weathering of sedimentary rocks characterized by a high percentage of aluminium-bearing minerals. Bauxites contains 40-60% of alumina, combined with silicon dioxide, iron oxides, and titanium dioxide. The major bauxite deposits of the world are found in Australia and in the tropical areas of Latin America and Africa (Table 6).

Table 6. Worldwide bauxite extraction per country and related overburden

Country	Bauxite extraction (1000 t)	%	Overburden (t over/t bauxite)
Australia	55 600	38.1	0.2
Guinea	15 500	10.6	0.2
Jamaica	13 400	9.2	0.05
Brazil	13 100	9.0	0.9
China	12 500	8.6	6.6
India	10 000	6.9	0.2
Venezuel	5 200	3.6	0.1
Suriname	4 220	2.9	0.3
Russia	4 000	2.7	-
Greece	2 420	1.7	14
Guyana	1 500	1.0	7.5
Others	8 500	5.8	-
World	**145 940**	**100.0**	**1.11 (average)**

Source of data: U.S. Geological Survey, 2005. Overburden estimates from Roullier, 1990.

The bauxite is mined, screened and washed to remove fine particles, before being transferred to alumina production facilities.

It shows the entire bauxite-to-aluminium process (Bargigli [20]), although the subsequent steps of bauxite transformation to alumina and beyond are not included in present analysis.

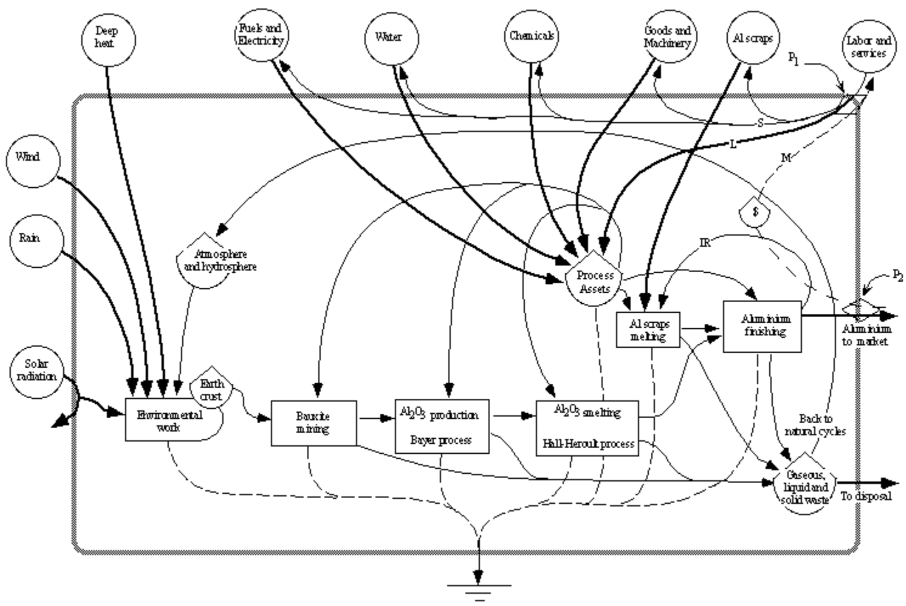


Figure 6. Systems diagram of bauxite-to-aluminium production, showing the main renewable, non-renewable and feedback flows supporting the process

4.3. Results and discussion

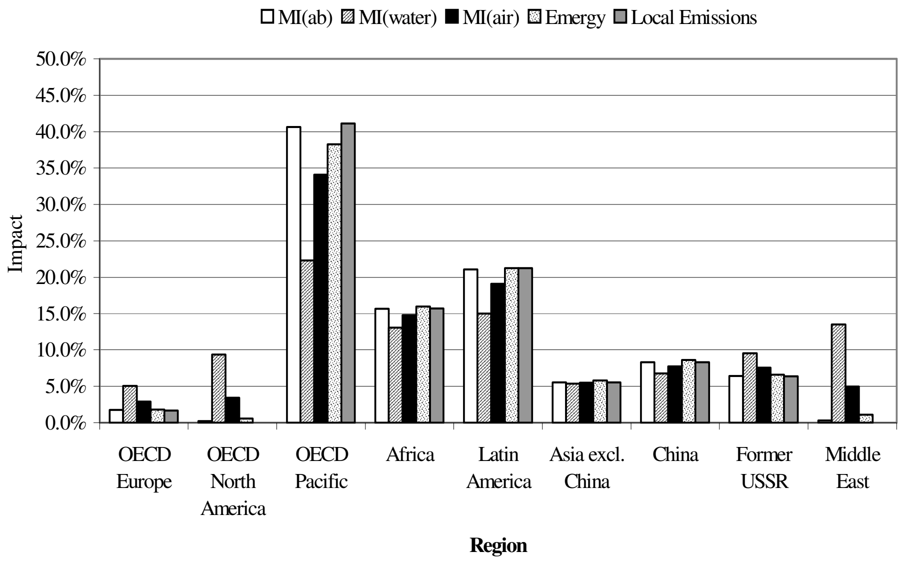


Figure 7. Complete percentage break-downs of all the considered environmental impact indicators for the different world regions (MI stands for Material Intensity)

As explained in the Method section, the allocated proportions of the considered environmental impact indicators are determined by the localization of the mines, as well as, to a lesser extent, by the use of fuels. The inclusion of the emergy inputs due to goods and services further refines the picture, but does not alter the qualitative results. Complete percentage break-downs of all the considered environmental impact indicators (MI abiotic, MI water, MI air, specific emergy and local emissions) are then illustrated in the histogram plot of Figure 7.

It is important to underline that the histogram shows the geographic allocation of each indicator to the different world regions, expressed as percentage of the total. Therefore no comparison among the absolute values of differently-coloured histogram bars should be attempted, but only relative-value comparisons, which are indicative of which are the categories in which a specific world region is more impacted.

In first approximation, the regionalisation of the impacts essentially mirrors the geographic distribution of mineral production itself. This is a foreseeable result, since the object of analysis is a primary production process which mostly exploits locally-available inputs. As far as the next process steps are investigated, the regionalisation may show different patterns, specific for each investigated process.

It is however interesting to note how the various impact indicators are allocated for those world regions where no bauxite production takes place (i.e. North America and Middle East). In fact, since no local inputs are used in these regions, all the impact associated to them are due to the fact that they are fuel producers (in the case of emergy, there is a further contribution caused by the associated money flows). In particular, non-negligible percentages of the MI factors relative to water and air are attributed to these regions (North America and Middle East), since these factors are largely determined by the direct and indirect requirement of fossil fuels. On the contrary, the MI factor relative to abiotic matter is not influenced as much by the fuels, since the local contribution due to the mineral and overburden is much higher. Hence the low percentages of allocation of abiotic MI to these regions.

The proposed allocation procedure is a promising and versatile tool in highlighting the geographic distribution of the environmental load of the production of primary commodities. In particular, our preliminary results have shown that the procedure is able to correctly trace all the material and emergy requirements for mineral production back to their regional origin, also considering fuel and monetary flows.
In the analysed case study the results are still largely dominated by the regionalisation of the mining activity itself, but the picture can become more complicated (and more interesting and rich in information) in the case of other activities that entail larger electricity and/or direct fuel requirements, and in the case of subsequent transformations of the extracted mineral (e.g. alumina and aluminium production from bauxite).

5. CONCLUSIONS

We have shown in this paper that fairness of trade and resource exchange among developed and developing countries is hardly expressed by monetary indicators as well as by the conventional terms of trade. This is because money does not measure a large set of free environmental services, which are embodied in the exchanged resources and goods, and therefore it is unable to assess the existence of unfair trade and unbalanced resource flows.

It is therefore of paramount importance that governments, trade operators, non-governmental organizations (NGOs), and consumers realize that there are other parameters and performance indicators which must be taken into account in order to better gauge the real value of resource exchange and the dynamics of the transfer of wealth among countries. The very environmental and social stability of the world depends on balanced exchange and equitable trade.

Our paper investigates the hidden flows of matter, energy and environmental services which support international monetary transactions. We maintain that these indicators should be first identified and individually calculated, and then be aggregated into larger-scale indices (such as material intensity, ecological footprint and emergy indicators), in order to provide a more comprehensive picture to complement monetary evaluations.

Finally, we show that trade equity does not only consist of exchanging resources fairly, but also of taking into proper account the existence of environmental and depletion factors which affect some regions more than others (e.g. the producers more than the buyer, the refiner more than the primary producer). When each performance and environmental indicator is disaggregated by world region, we are able to single out those areas which suffer from uncompensated resource depletion or environmental load, and may be able to suggest balancing policy and fair trade measures.

The emergy advantage to the buyer calls for fair trade, international cooperation, transfer of know how, in order to avoid the unbalance of resource exchange between countries.

The geographical allocation of impacts and resource depletion indicates the existence of a generalised interdependence of all nations, and calls for international agreements aiming at adequately compensating for environmental and resource burdens.

In both cases a large effort is required to create reliable databases for resource production and resource trade as well as to update the existing evaluations, in support of fair policy. Neoclassical economics and “free market” monetary mechanisms seem to be unable to solve the problems of poverty, pollution, and resource depletion. Most often these problems are generated by “free market” itself and keep growing. Alternative and integrative solutions are urgently needed and require coordinated research and policy actions. Worldwide collaboration beyond just market systems of value would help escape instability and reverse the trend, towards sustainable production and consumption.

References

[1] Odum H.T.. Emergy and Policy. Vol.1, pp. 25-29. Environmental Engineering Sciences, University of Florida, Gainesville, FL, 1994

[2] Sampat, P. Scrapping Mining Dependence. In: The State of the World, 2003, The World Watch Institute. Pp. 110-135, 2003.

[3] UNCTAD. Handbook of World Mineral Trade Statistics 1994-1999. New York, 2001

[4] World Bank. World Development Indicators 2001. Washington, DC, 2001.

[5] UNDP. United Nations Development Program, Human Development Report 2001. New York, 2001

[6] Ulgiati, S., Raugei, M., and Bargigli, S.. Overcoming the inadequacy of single-criterion approaches to Life Cycle Assessment. Ecological Modelling, (available on line, www.sciencedirect.com, 11 July 2005).

[7] Raugei M., Bargigli S., Ulgiati S. Evaluating molten carbonate fuel cells by means of thermodynamic performance and LCA impact categories. In: Proceedings of 3rd Advances in Energy Studies. Reconsidering the Importance of Energy, Porto Venere, Italy, 2003.

[8] Bargigli S., Raugei M., Ulgiati S.,. Comparison of thermodynamic and environmental indexes of natural gas, syngas and hydrogen production processes. Energy. The International Journal, 2004; 29: 2145-2159.

[9] Raugei M., Bargigli S., Ulgiati S. A multi-criteria life cycle assessment of Molten Carbonate Fuel Cells (MCFC). A comparison to natural gas turbines. International Journal of Hydrogen Energy, 2004; 30: 123-130.

[10] Simoncini E., Raugei M., Ulgiati S. Life Cycle Assessment of Synthetic Rutile Production Using The Erms/Ears Process. In: Proceedings of 2nd International Conference on Sustainable Development Indicators in the Mineral Industry, Aachen, Germany, 2005.

[11] Cherubini F., Bargigli S., Raugei M., Ulgiati S. LCA of Magnesium Extraction and Processing. Technological Overview. In: Proceedings of 2nd International Conference on Sustainable Development Indicators in the Mineral Industry, Aachen, Germany, 2005.

[12] Hinterberger F. and Stiller H. Energy and Material Flows. In: Advances in Energy Flows in Ecology and Economy. Ulgiati S., Brown M.T., Giampiero M., Herendeen R.A., and Mayumi K. (Eds). Musis Publisher, Roma, Italy; pp. 275-286, 1998.

[13] Bargigli S., Raugei M., and Ulgiati S. Mass flow analysis and mass-based indicators. Handbook of Ecological Indicators for Assessment of Ecosystem Health. CRC Press, 2004.

[14] Odum H.T. Environmental Accounting: Emergy and Environmental Decision Making. John Wiley & Sons, N.Y, 1996.

[15] Brown, M.T., and Ulgiati, S.. Emergy Analysis and Environmental Accounting. In: Encyclopaedia of Energy, C. Cleveland Editor, Academic Press, Elsevier, Oxford, UK, pp.329-354, 2004

[16] Ulgiati, S. and Cialani, C., 2005. Environmental and Thermodynamic Indicators in Support of Fair and Sustainable Policy Making. Investigating Equitable Trade among Latvia, Denmark and Italy. In: Baltic Sea Region Sharing Knowledge Internally, Across Europe and Worldwide. Series on Environmental Education, Communication and Sustainability. Walter Leal Filho/Arnold Ubelis (eds.). Peter Lang Publisher, Frankfurt am Main, Germany, 2005 (in press).

[17] La Repubblica, 2005. La mela cinese (Chinese apples). Article by F. Rampini and J. Meletti. Issue 12th June 2005, pp.27-29. See also: http://www.fruitecom.it/rassegnastampa/download/.

[18] Brown, M.T. Resource Imperialism: Emergy Perspectives on Sustainability, International Trade and Balancing the Welfare of Nations. In: Book of Proceedings of the International Workshop "Advances in Energy Studies. Reconsidering the Importance of Energy". Porto Venere, Italy, 24-28 September

2002. S. Ulgiati, M.T. Brown, M. Giampietro, R.A. Herendeen, and K. Mayumi, Editors. SGE Publisher Padova, Italy, pp. 135-149, 2003.

[19] Pengue, W. Externalities and Transgenic Crops released in The Pampas: An Ecological Economics Approach. Book of Proceedings of the IV Biennial International Workshop “Advances in Energy Studies”, 16-19 June 2004, Campinas, Sao Paulo, Brasil, 2004.

[20] Bargigli S., 2004. Enhancing MFA And LCA Techniques by Means of Integrated Upstream and Downstream Flow Evaluation. The Case of Aluminum Production. In: Book of Proceedings of the International Conference "Integrative Approaches towards Sustainability in the Baltic Sea Region - Environmental Education, Communication and Sustainability. vol. 15, pp. 491-499. Peter Lang Europäischer Verlag der Wissenschaften – Frankfurt am Main. Walter Leal Filho/Arnold Ubelis (eds.), 2004.