Material flow accounting of an Indian village

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Abstract: We are presenting material flow accounting and related indicators for an Indian adivasis village in 1983 (Sarowar, Dangs, Gujarat). It gives a point of comparison with modern nation-wide material flow accounting. The aim is to test the feasibility of indicators of dematerialization of the economy in poor economies. We measured the annual material flows within the Sarowar village (670 inhabitants) in 1982-1983. The method was a combination of surveys, real time measurements, indirect measurements and laboratory dry matter measurements. The results were translated into recent concepts of material flow accounting (MFA), and compared with nation-wide studies. The total material requirement (TMR) of Sarowar (excluding air and water), USA, Japan, Germany and The Netherlands is respectively about 5, 84, 46, 86 and 84 tons per capita per year. The input (all biotic materials are expressed in tons of dry matter per capita per year) totalised 15,8 t DM cap-1 y-1 in Sarowar, which consists mainly of air (11 t cap-1 y-1) and biotic primary materials (4,1 t DM cap-1 y-1). The latest was composed of 29% of pastures, 25% of branches for field burning, 35% of fuel wood, 6% fodder, 1% of construction wood and 4% of grains. The outputs (15.8 t cap-1 y-1) were dominated by CO_2 (15.1 t cap-1 y-1). In contrast, the output of The Netherlands (66.8 t cap-1 y-1) is dominated by export with air emissions (19 t cap-1 y-1), export (16 t cap-1 y-1) and embedded export (29 t cap-1 y-1). The apparent ecoefficiency (kg per US dollar, excluding air and water, including hidden flows) is 70, 3, 3, 3 and 3 kg $-1 respectively for Sarowar, Japan, USA, Germany and The Netherlands. The corrected ecoefficiency using Purchasing Power Parity is less contrasted with respectively 18, 3, 3, 4 and 3 kg $-1. Traditional human ecosystem measurements can serve as a basic comparison point, and as a test for dematerialization indicators. The limit of the indicator of ecoefficiency resides in the different degrees of monetarization of the economies. In less monetarized economies, this indicator is highly biased by the underlying non-market material flows. We discuss the use of ratios of non-substituable factors in dematerialization assessment and we suggest the use of use multicriteria analysis instead.

Cover letter: Revision of "Material flow accounting of an Indian village"

To: Biomass & Energy

Date: 10/5/7

Dear editor and referees,

Thanks for your suggestions.

<u>Fundamental suggestions:</u>

I added a paragraph and some references on quality of air emissions resulting from incomplete combustion of open burning (in the discussion), and a sentence in the conclusion.

I also mentioned the quality critic in solid flows in general.

I added some more details in the "Material and method" chapter and in the discussion part.

<u>Style suggestions</u>:

I changed the format of units (using t y^{-1} for example).

I moved old footnotes to the core text.

An English native speaker corrected English.

I explained the acronyms within the summary and in various parts of the text.

I added some keywords.

Best regards,

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Material flow accounting of an Indian village

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Abstract

1. We are presenting material flow accounting and related indicators for an Indian adivasis village in 1983 (Sarowar, Dangs, Gujarat). It gives a point of comparison with modern nation-wide material flow accounting. The aim is to test the feasibility of indicators of dematerialization of the economy in poor economies. We measured the annual material flows within the Sarowar village (670 inhabitants) in 1982-1983. The method was a combination of surveys, real time measurements, indirect measurements and laboratory dry matter measurements. The results were translated into recent concepts of material flow accounting (MFA), and compared with nation-wide studies. The total material requirement (TMR) of Sarowar (excluding air and water), USA, Japan, Germany and The Netherlands is respectively about 5, 84, 46, 86 and 84 tons per capita per year. The input (all biotic materials are expressed in tons of dry matter per capita per year) totalised 15,8 t DM cap^{-1} y^{-1} in Sarowar, which consists mainly of air (11 t cap^{-1} y^{-1}) and biotic primary materials (4,1 t DM cap^{-1} y^{-1}). The latest was composed of 29% of pastures, 25% of branches for field burning, 35% of fuel wood, 6% fodder, 1% of construction wood and 4% of grains. The outputs (15.8 t cap^{-1} y^{-1}) were dominated by CO_2 (15.1 t cap^{-1} y^{-1}). In contrast, the output of The Netherlands (66.8 t cap^{-1} y^{-1}) is dominated by export with air emissions (19 t cap^{-1} y^{-1}), export (16 t cap^{-1} y^{-1}) and embedded export (29 t cap^{-1} y^{-1}). The apparent eco-efficiency (kg per US dollar, excluding air and water, including hidden flows) is 70, 3, 3, 3 and 3 kg $\$^{-1}$ respectively for Sarowar, Japan, USA, Germany and The Netherlands. The corrected eco-efficiency using Purchasing Power Parity is less contrasted with respectively 18, 3, 3, 4 and 3 kg $\$^{-1}$. Traditional human ecosystem measurements can serve as a basic comparison point, and as a test for dematerialization indicators. The limit of the indicator of eco-efficiency resides in the different degrees of monetization of the

economies. In less monetized economies, this indicator is highly biased by the underlying non-market material flows. We discuss the use of ratios of non-substitutable factors in dematerialization assessment and we suggest the use of use multi-criteria analysis instead.

Introduction

The Resource Flows [1, 2] concept developed by the World Resources Institute, addresses the Total Material Flow (TMF) underlying the economic process. The set of indicators that it produces has a certain political success among OECD countries. The European Commission is for example drafting a Regulation that would oblige the National Statistical Institutes to produce material flow accounting for each country. A Material Flow Accounting framework can be applied on several spatial scales, from supra-national entities to sectors, cities or regions [3]. It can also be used for temporal or historical comparison.

The idea is to tend towards a more efficient and sustainable development: to produce more human well being using less natural resources, i.e. decoupling economic growth from material use. This idea comes from the recognition that there is a material (natural) limit to growth [4-6].

Measuring the environmental/economic decoupling combines classical methods from economics (how to measure economy?) and from human ecology. For precursor studies of human ecology, see Odend'hal[7] and Duvigneaud[8].

The Total Material Requirement (TMR) measures the global pressure of primary matter on natural systems by summing the primary matter input expressed in tons, including the ecological rucksacks [9]. A light version of these accounts distinguishes the Direct Material Input (TMR minus hidden flows) and the Total Material Output that includes emissions (in air, water, waste) and goods exports. In omitting hidden flows (thus the impact of imports on material extraction in the rest of the world), this light version is not suitable for deriving sustainability indicators, since an apparent dematerialization could occur in case of dislocating of heavy productions to the rest of the world. However, in an international statistical work, such an approach could be cheaper to conduce, providing the TMR afterwards is calculated by consolidating the results of all trading countries together. The hidden flows are typically associated with extraction activities, harvesting or infrastructure development [1]. Eurostat distinguishes the foreign hidden flows (or indirect flows, associated with import-export of primary matter), and domestic hidden flows (unused extraction) [10]. TMR is generally calculated excluding water flows but with biotic material expressed in fresh weight, which is debatable. Air flows are often excluded from the TMR indicators, the exclusion of which is also debatable in a context of a problematic atmospheric cycle. The main reason to exclude air and water flows, or at least to present them separately, is that they represent enormous mass flows (one order of magnitude more than other materials)[10].

The first national studies in developed countries show that, for example in Germany [11],
-About 50% of the Direct Material Input comes from outside the country, 50% from domestic environment
-The material input is of an abiotic nature, mainly solid (from which there is a non-used part) and about 15% gaseous (mainly O_2, N_2)
-About 15% of the input is used to raise the material stock in economy, the remaining part being emitted in the environment (or marginally exported).
-These emissions are mainly solid (about 60% land filled waste), gaseous (about 25%, mainly CO_2) and to water (about 10%)
-The recycling is small

Few traditional village level ecosystem studies had been published in the time of our field research: a study of a Bengali village [7], another in Gujarat [12], in Tamil Nadu [13], in Karnataka [14-16], two in Africa [17, 18], and several village studies in China from 1978 onwards. Recent works concentrate either on agricultural practices [19, 20] or energy efficiency [21-26]. Some "pure" ecosystem [27] or material flows studies [28] were published more recently, always with socio-economic or sustainable development goals. Village-level studies on ecosystem functions [29] are also relevant.

Material and method

We tested the method and indicators for the case of Sarowar (N 20°50'21", E 73°36'31"), a quasi-autarkical Indian village, situated in the mountains of the State of Gujarat, in the Dangs district, on the road Ahwa-Pimpri-Sarowar-Kalibel-Vyara, 30 km from Ahwa.
The Dangs district is a hilly area with several plateaus ranging from 300 to 700 m of altitude[30]. It makes the transition between the Gujarat plain and the Sahyadris Mountains. The rock is basaltic (Deccan trap). The mean temperature in Ahwa (549 m) is 24, 9°C and the mean rainfall is 2076 mm. The rainy season lasts 5 months (May-September), the dry season 7 months. According to Köppen's classification, the climate is of type Aw 7-8 with a tendency to Am (monsoon). The hills are covered with a forest of teak (*tectona grandis*) and

bamboo (*dendrocalamus strictus*). According to Champion's classification, it is a South Indian tropical wet deciduous forest (group 3A), a subdivision Semi-humid teak forest[30]. Exploitable trees are mainly teak (54% of trees of circumference bigger than 120 cm), *terminalia tomentosa,* and *pterocarpus marsupium*. Other common trees are *garuga pinnata* and *lannea coromandelica*. Climbing plant species are numerous, with *millettia racemosa*, *butea superba* etc. More than 300 medicinal species were identified, of which about 100 were used[30].

One can distinguish dry and clear forest[31]. At the time of the study (1982-1983), all the land was either reserved or protected. In the reserved forest, limited tree exploitation was a monopoly of the government but the people were allowed to trim the trees once a year and use the branches for fertilizing their fields. The protected forest was a natural reserve financed by the World Wildlife Fund, with a prohibition of agriculture and some limited timber exploitation by government. This special status was justified by the presence of tigers (*Panthera tigris*). Other noticeable mammal species were *panthera pardus, melursus ursinus, sus scrofa, hyena hyena,* and *cervus unicolor*. More than 120 bird species were identified in the district[30].

The peasants were not allowed to cut the trees, which were governmental property. They cut the branches and burned them onto the field with the purpose of pest control and fertilizing (like in shifting cultivation) but without the inconveniences of clear-cut (erosion, declining fertility etc). This method is called *essartage* in French (the English term *fire agriculture* is not appropriate).

Animist tribes, mainly Kokeni, Warelis and Bihls, and a few non-tribal civil servants coming from other parts of Gujarat inhabited Sarowar village. The population was 692 inhabitants corresponding to an equivalent of 670 full time inhabitants (taking into account their rate of presence in the village). They could benefit from a luxurious forest, either directly or indirectly via their cattle, which could freely pasture within it. The cultivated area per capita in different households varied between 0.15 and 1.7 ha cap^{-1} with a mean of 0.7 ha cap^{-1}.

Animal traction was the main purpose of animal breeding, along with milk production – the residents were mainly vegetarians and limited the meat (chicken) consumption to animist ceremonies. The total annual revenue of Sarowar was estimated 465819 INR (70% of it expended in local shops)[32]. The exchange rate was 10 INR per USD in 1983 [33] which gives a mean monetary revenue (in 1983 prices) of 70 \$ cap^{-1} y^{-1}.

We used previous data that we collected in 1982-1983 [32, 34]. At that time, we intended to describe a rural human ecosystem. We collected data using different methods, from direct measurement to surveys among the inhabitants, and literature. We stayed 7 months in the village during the dry season. The surveys by interview consisted in a combination of a census for quantitative data (population, cattle, agricultural products etc) and a sample for measurements (house, kitchen garden, fuel wood, etc) or open questions on the consumption pattern. We identified four main socio-economic classes: landless farm workers, farmers, civil servants and others. This was then used as post-stratification in order to extrapolate our sample results. We weighed a representative sample of people (20% of the population) in order to calculate the total anthropomass using a function of sex and age pyramid. This was a pleasant way to introduce the interviews in many households. Combined with the typical labour force patterns, this was useful to estimate the feeding energy needs using FAO-WHO tables[35]. The three shopkeepers were all surveyed on their annual imports, exports and sales in quantity and prices.

The field measurements consisted on transects to estimate the land pattern, and field sampling to estimate the productivity. During the dry season, it is possible to collect data both about harvesting (and related primary productivities) and about the preparation of fields (mainly branch cutting for burning in the fields). We followed farmers and workers during the harvests in order to measure the quantities collected per ha, the relation between grains and other parts of the plants, the quantities taken away or released onto the field etc. From grain, fodder and wood quantities estimated from the census, it was thereafter possible to calculate various ecosystem flows. Samples of diverse biotic flows and stocks were also taken away for laboratory analysis (dry matter and main chemical elements) later on. The quantities measured (with a great variability amongst fields and time of harvest) were useful to validate the survey results and deductions.

We translated this data into a conventional ecosystem flow chart, then into modern material flow accounting concepts.

Results

The biotic materials represented the major part of the inputs of the economy as defined by the village Sarowar, its fields and the used part of its natural environment. If we had limited the study to marked exchanges, the flows would have been negligible in this largely autarkic economy. Figure 1 represents the material flows within this ecosystem, expressed in tons of dry matters. We distinguished the subsystem "village" with its kitchen gardens (15 ha), the fields (subsystem "ager", 239 ha), and the natural and semi-natural areas including the forest and pastures (subsystem "silva+saltus", 206 ha). The domestic animals (and marginally humans and wild animals) travel from one subsystem to the other and represent the connecting elements. Permanent forest cover and traditional agricultural practices relatively limited erosion. However, with potential alternative management such as deforestation and modern cultural practice, this element could become relevant in a possible future.

The ecosystem study showed the importance of forest products, mainly in the shape of firewood (892 tons of dry matter per year), pasture (estimated 740 t DM y^{-1}), branches for field preparation or *essartage* (640 t DM y^{-1} from forest and field trees) and wood export by the forestry company (200 t DM y^{-1}) [34].

We measured a significant higher yield of paddy in the surrounding of isolated trees (2.65 t DM ha^{-1}) than in semi-open land (2.25 t DM ha^{-1}) of the same plot. Open land yields in other plots of the same village provided respectively 500 and 700 kg paddy (dry matter) per ha.

Translated into the terminology of material flow accounting, the results of this study provide the data presented in table 1. The data from Netherlands is presented in the same table in order to give an element of comparison. The economic space is defined here everything that has to do with humans, the village or domestic animals. The fodder flows within the forest are therefore included, but the nutriments taken by the plants within the soil are not included because it represents a natural service almost independent from direct human activities. This distinction can be debated, but it does not change fundamentally our results. We keep the dry matter unit: for biotic flows, this restriction avoids the fluctuations due to wet content variability. If long distances were involved, for instance, on the level of a country, the use of fresh matter could be justified from a transport problem point of view. Water flows are omitted in both results, following European recommendations [10].

The main difference in MFA between Sarowar and the Netherlands is observed in import/export, which is linked to the degree of opening of these economies. The Sarowar village is less open to the outside economy than the full (small) developed country.

As expected, the autarkical village consumes more primary biotic material per capita (4.1 t DM cap^{-1} y^{-1}) than the Netherlands (0.4 t DM cap^{-1} y^{-1}). This is due to a relatively extensive use of luxurious natural resources in contrast with the relatively efficient use of domestic scarce natural resources in a very densely populated country like the Netherlands (470 cap km^{-2}, against Sarowar 136 cap km^{-2}). You can note that, due to the protection status of the Dangs forest, and the prohibition of tree cutting, the natural system was far from over-exploited in Sarowar. Compared with traditional extensive cultivation in equatorial Africa (shifting cultivation), this cultivation system is relatively intensive and efficient. We are thus not comparing a full extensive system with an intensive one, but a “traditional” intensive system with a modern one.

We consider the erosion due to traditional practice as comparable with the background natural erosion in this hilly area (possible 24.15 t ha^{-1} y^{-1} are not taken into account as economic flows). This estimation is empirically based a detailed study in a Chinese context: an erosion of 24.15 t ha^{-1} y^{-1} with traditional cultivation techniques, compared to 42.21 t ha^{-1} y^{-1} from other plot monitoring studies in a similar area, shows that the traditional farming system has effectively conserved soil on the slope land there in the past decades [19]. With a modern or extensive shifting cultivation scheme, Sarowar would probably add about 18.06 t ha^{-1} y^{-1} erosion, or 4316 t on the fields, and 5 t cap^{-1} additional material requirements.

The atmospheric inputs and outputs are remarkably of the same order of magnitude between the compared systems. In order to build comparable results with the Netherlands, we only included O2 as an input and CO2 as an output. However, CO2 as an input of biotic production and O2 as its output could be included in both systems, as beneficial material flows: “natural service production” for the economy. Concerning Sarowar, the volume of atmospheric inputs and outputs is due to the wood incineration for cooking or field fertilizing. If the cooking is relatively efficient due to the work cost necessary to transport wood from the forest to the village, the field burning of branches supposes a “non efficient” use, from the point of view of energy efficiency.

The important use of domestic animals as source of milk, power force and high quality fertilizers explain the major part of the non-energetic material flows identified in Sarowar.

The stock variation of the economy is remarkably low in Sarowar (+0.1 t cap^{-1}) if compared to the Netherlands (+5.0 cap^{-1}).

Discussion

The literature on material flow accounting tends to concentrate on solid and product flows, expressed in total absolute weight. We are far from traditional human ecosystem studies, which quantify many possible flows. This choice is driven by the policy-oriented nature of material flow analysis: limiting the analysis to the impacts of the economy (i.e. human activities). The further limitation to non-air and non-water flows is driven by pragmatism: it is cheaper to exclude many flows in a first analysis. Moreover, on a national scale, solid or product flows are easier to estimate from existing trade and production statistics. Air and water flows are of a greater magnitude and their exclusion helps to focus attention on more “qualitative” material flows included in solids and products. However, the qualitative aspect is certainly not addressed in solid and product material flows, which remain dominated by, for example, inert materials from construction. Qualitative material flows are of greater importance for the environment. For example, flows of toxic compounds can have greater environmental or health impacts than big amounts of stones or grounds. From this point of view, we think that air and water should not be excluded from (even quantitative) material flow analysis or "social metabolism" studies. The transportation of pollutants in air or water is certainly more relevant from the health or environmental perspective than the transportation (by economy) in solid forms. If material flow analysis could help as a first approach to the impact of economy on the ecosystem, therefore we think that air and water flows should not be excluded. Human perturbation of water and atmospheric cycles are two of the major global problems today [36, 37].

A first quantitative study including air flows, such as the one we did for Sarowar, should not elude the hidden problematic of qualitative flows. For example, open burning in "essartage" would engender, in terms of particulates and products of incomplete combustion (on health and on climate change), effects considerably greater than the sole CO2 emissions [38-41]. On the other hand, if technology and for example improved hooves [42] could increase the eco-efficiency of specific processes such as burning in developing and developed countries, the latter could have, and actually have, a bigger impact on global environment [36, 43, 44] due to a bigger quantitative material intensity.

It is questionable whether field burning should be included or excluded from the economic process, since this only shortens the natural cycle (the related emissions would anyway end within the ecosystem). The recent European waste statistics regulation for example excludes the within farmland ecosystem recycling from the waste incinerations statistics [45]. For the same reason as above, we plead for the including of all human activities and related services of nature in material flows accounting. Omitting any direct or indirect flows for pragmatic reasons increase the part of "hidden" flows, the ones that could precisely be the most relevant from a perspective of local or displaced impacts.

The total material flow (TMR) per capita measures the efficiency of the contribution of the population to its economy. This is certainly the most relevant indicator if we want to compare a market economy (a "developed" country) with an autarkical village whose economy is only marginally monetized. TMR could also be divided by hectares or by gross domestic product. For further discussion, let us use here the same metric for TMR as in reference studies (excluding air and water, including hidden flows) in order to be able to discuss the most popular eco-efficiency indicators. The TMR per capita per year was 5 t cap^{-1} y^{-1} in Sarowar, against respectively 84, 46, 86 and 84 t cap^{-1} y^{-1} in USA, Japan, Germany and Netherlands (table 3). The intensity of material requirement per surface is only 7 t ha^{-1} for Sarowar, against respectively 22, 151, 189 and 307 t ha^{-1} for the developed countries considered. Note that for Sarowar, this amount is of the same order of magnitude as the potential net primary productivity of the agro-ecosystem, as measured in an associated culture of sorghum, beans (*dolichos lablab*), maize and fibre plants in a kitchen garden (7.1 t ha^{-1}). In developed countries, the larger amount can be explained by a potentially quicker turnover of non-biotic material flows.

The common indicator of eco-efficiency or material intensity (TMR per unit of GDP) provides contrasted results. Following this indicator calculated on the basis of GDP at the current exchange rate, the tribal village of 1983 seemed much less efficient than developed countries of 1991. Its denominator (GDP) being very small because of the low monetization rate of its economy, and its material inputs being relatively high in its context of luxurious nature, its TMR/GDP is immense: 70 kg \$$^{-1}$, compared to the 3 kg \$$^{-1}$, 3.4 kg \$$^{-1}$, 3.3 kg \$$^{-1}$ and 3.2 kg \$$^{-1}$ respectively for Japan, USA, Germany and the Netherlands. Thus, to produce 1 dollar of monetary revenue, Sarowar seemed to use 20 times more material than The Netherlands. For cross-country comparison of GDP, the use of Purchasing Power Parity is more appropriate [46]. The UN SNA (System of National Accounts) defines a PPP as a price relative which measures the number of units in country B's currency that are needed in country B to purchase the same quantity of an individual good or service as what 1 unit of country A's currency will purchase in country A. Whereas the GDP of developed countries do not change much when applying PPP, the Indian GDP is corrected by a factor 4 [47, 48]. The comparable material intensity (in PPP) is then respectively 18 kg \$$^{-1}$, 3.4 kg \$$^{-1}$, 3.2 kg \$$^{-1}$, 3.7 kg \$$^{-1}$ and 3.4 kg \$$^{-1}$ for Sarowar, Japan, USA, Germany and the Netherlands. Yet, the material intensity of the tribal economy, expressed in PPP, was still 6 times bigger than in modern economies. It should be noted that Sarowar was relatively well monetized if compared with surrounding villages not accessible by road. An ancestral economy with no money would give an infinite material intensity following this calculation.

Given the assumption that GDP does not represent the reality of the economy (in terms of providing goods and services for human well-being), neither in autarkical villages, nor in modern economies, a suitable solution could be to use an adjusted GDP, as a denominator to calculate the material intensity. This adjusted GDP[49-53] would for example exclude defensive expenditures (which is important for developing countries) and include a monetization of autarkic work. For example, in the works on adjusted GDP, the monetization of household labour is taken considering local rates for housekeepers. Since rates for housekeepers are not comparable between countries, this would introduce another type of bias. In order to give comparable results between countries, a hypothetical adjusted GDP would, in turn, need to be calculated in PPP. We do not enter into the debate on adjusted GDPs here.

The calculation in this study shows the limits of the economic efficiency concept applied to non-market economies. Moreover, even market economies include significant non-market economic flows [49-54]. Here we can directly question the global relevance of the concept of dematerialization of the economy as expressed by TMR/GDP. Following this indicator, developed countries would be, by far, in advance, regarding dematerialization, even if they remain the biggest users of materials from a global (absolute data) and relative (per capita) point of view. We have seen (table 3) that per capita, the tribes of Sarowar use about 10-16 times less material than the mean Occidental inhabitant, and even 5-10 times less if only direct input (grand total commodities) is taken into account. We show in the last row of table 3 a possible wrong comparison of apparent intensity of air used (related to intensity of carbon emission), where Sarowar seems 100 times more air-intensive than developed countries. The apparent air use (thus the CO2 emissions) per capita is of the same magnitude than the per capita use (or emissions) of industrial economies. The difference is however qualitative since we have in Sarowar renewable air uses, thus accounting for zero in greenhouse gas accounting. This kind of comparison would be twice wrong: wrong for the numerator (comparing recyclable use to irreversible use) and wrong for the denominator (using GDP as a measure of the economy).

The concept of intensity, using two different units in the same ratio, implies the hypothesis of substitutability between factors. For example, reducing TMR or increasing the population can obtain reducing the TMR per capita. Reducing the TMR or increasing the GDP can obtain reducing the TMR per GDP. Is it good for sustainable development to increase the population or the GDP? This fundamental question is not raised in these kinds of ratios.

Acknowledging that the GDP is not a relevant measure of life satisfaction [55], one can suggest using the concept of dematerialization of life satisfaction, of human well being, of human development or of any corrected GDP, in dematerialization studies. Using different dimension, not mixing different indicators in the same ratio, avoids the illusion of perfect substitutability between the economy and the environment. The goal being to reduce the material impact of whatever human ideal, these two indicators (environment and human well-being) should remain in separate dimensions. Examples of multidimensional tools are the multi-criteria analysis [56] or graphic representation where human well-being and ecological well-being are presented side by side like in Prescott Allen [57].

Conclusion

We presented a material flow accounting of a semi-autarkic Indian village, based on a former human-ecological survey. Such material is available in other studies in human ecology. Traditional human ecosystem measurements can serve as a basic comparison point, and we used it to test common dematerialization indicators. We showed the importance of counting as much direct and indirect flows as possible. In particular, hidden flows, embedded in imports and exports, and air flows can be important from their impact point of view. Water flows should be included for the same reason. Qualitative aspects should always be evaluated. For example, open burning is associated to incomplete combustion and greater toxic emissions. We showed that the limit of the eco-efficiency indicator mainly resides in the different degrees of monetization of the economies. In incompletely monetized economies, this indicator is highly biased by the underlying non-market material flows. We question the use of ratios of non-substitutable factors in dematerialization assessment and we suggest the use of multi-criteria analysis instead.

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Tables

Table 1: Material flow accounts of Sarowar 1983, compared with the Netherlands 1991

	Sarowar (t DM)	Sarowar (t cap^{-1})	Netherlands (t cap^{-1})
INPUTS	10603	15,8	84,9
Imports	120	0,2	20,2
Foreign hidden flows	360	0,5	42,1
Abiotic raw material	0	0,0	12,3
Biotic raw material (dry weight)	2761	4,1	0,4
Air	7363	11,0	9,8
Erosion	0	0,0	0,1
Recycling			-2,3
Hidden flows avoided by recycling			-2,7
ECONOMY			
Stock variation	+40	+0,1	+5,0
OUTPUT	10564	15,8	66,8
Exports	208	0,3	15,8
Waste disposal (excl. Incineration)	5	0,0	1,7
Erosion	0	0,0	0,1
Waste (biotic), water emissions	220	0,3	0,7
Air emissions	10124	15,1	19,4
Hidden flows export	8	0,0	29,1

Sources: authors and [1]

Here, the biotic material for The Netherlands is here expressed in dry weight estimating 31% of dry matter in an average of grains and grass production for this country (see table 2)

Table 2

Biotic material requirement (1000 metric tons) in The Netherlands 1991.

Renewable			
1. Plant Biomass (fresh weight)	% DM	Fresh weight	Dry weight
Grass	20%	8946	1789
Wheat	88%	1144	1007
Rye	88%	41	36
Barley	88%	288	253
Oat	88%	22	19
Peas	88%	39	34
Bean	88%	11	10
Cole seed	88%	25	22
Flax	88%	135	119
Potatoes	20%	20435	4087
Potatoes (industrial)	20%	8886	1777
Sugar beets	20%	28756	5751
Onion	10%	4466	447
Corn (for cattle)	60%	35660	21396
Vegetables	20%	24962	4992
Fruit	20%	2100	420
II. Plant Biomass, Wild Harvest Wood	88%	551	485
II. Animal Biomass, Wild Harvest Fish	30%	740	222
Total Renewable	31%	137207	42867

Source: [1] for fresh weight, authors estimates for dry weights

Table 3: Comparison of material flows (excluding air and water) between a traditional autarkical Indian village (1983) and four developed countries (1991).

	USA	Japan	Germany	Netherlands	Sarowar	
Unit of raw data	t x 10^6	t x 10^6	t x 10^6	t x 10^6	t	
Total domestic commodities	4581	1424	1367	271	2761	
Total foreign commodities	568	710	406	303	120	
Grand total commodities	5149	2133	1773	574	2881	
Grand total commodities per cap (t cap^{-1})	20	17	22	38	4	
Domestic hidden flows	15494	1143	2961	69	0	*
Foreign hidden flows	594	2439	2030	632	360	**
Total hidden flows	16088	3582	4991	701	360	
Tot. Hidden flows/tot. Comm.	3	2	3	1	0,04	
TMR (commodities + hidden flows)	21237	5715	6764	1275	3241	
TMR per capita (t cap^{-1})	84	46	86	84	5	
TMR per GDP (kg $\$^{-1}$)	3,4	3,0	3,3	3,2	70	
TMR per GDP PPP (kg $\$^{-1}$)	3,4	4,2	3,7	3,4	18	
TMR per surface (t ha^{-1})	22	151	189	307	7	
Air***	3949	843	1095	149	7363	
Air (t cap^{-1})	14	7	14	10	11	
Air / GDP PPP (kg $\$^{-1}$)	0.6	0.4	0.6	0.4	41	

*Limited to erosion due to human activities. Supposed negligible in Sarowar at this time, due to cultivation on moderated slopes and terraces with associated cultivation and tree cover.

** Direct foreign input x hidden flow/indirect input of the USA (hidden flow from equivalent US exportation)

*** As an indicative proxy, air data for USA and Japan were calculated using the O2 equivalent of CO2 emissions (1997) given by [57]

Source: authors and [1]

Figures

[Separate file ecosystem4.jpg]

Figure 1: Ecosystem Sarowar (flows expressed in tons dry matters) after [34]

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