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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 CO₂ (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.

Fundamental suggestions:

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.

Style suggestions:

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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1 Material flow accounting of an Indian village

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6 Keywords: village ecosystem, material flow accounting, India, biomass, resource flows,
7 social metabolism, forest, dematerialization, indicators, impact, eco-efficiency

8 **Abstract**

9 1. We are presenting material flow accounting and related indicators for an Indian
10 adivasis village in 1983 (Sarowar, Dangs, Gujarat). It gives a point of comparison with
11 modern nation-wide material flow accounting. The aim is to test the feasibility of
12 indicators of dematerialization of the economy in poor economies. We measured the
13 annual material flows within the Sarowar village (670 inhabitants) in 1982-1983. The
14 method was a combination of surveys, real time measurements, indirect measurements
15 and laboratory dry matter measurements. The results were translated into recent
16 concepts of material flow accounting (MFA), and compared with nation-wide studies.
17 The total material requirement (TMR) of Sarowar (excluding air and water), USA,
18 Japan, Germany and The Netherlands is respectively about 5, 84, 46, 86 and 84 tons
19 per capita per year. The input (all biotic materials are expressed in tons of dry matter
20 per capita per year) totalised 15,8 t DM cap⁻¹ y⁻¹ in Sarowar, which consists mainly of
21 air (11 t cap⁻¹ y⁻¹) and biotic primary materials (4,1 t DM cap⁻¹ y⁻¹). The latest was
22 composed of 29% of pastures, 25% of branches for field burning, 35% of fuel wood,
23 6% fodder, 1% of construction wood and 4% of grains. The outputs (15.8 t cap⁻¹ y⁻¹)
24 were dominated by CO₂ (15.1 t cap⁻¹ y⁻¹). In contrast, the output of The Netherlands
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26 cap⁻¹ y⁻¹) and embedded export (29 t cap⁻¹ y⁻¹). The apparent eco-efficiency (kg per US
27 dollar, excluding air and water, including hidden flows) is 70, 3, 3, 3 and 3 kg \$⁻¹
28 respectively for Sarowar, Japan, USA, Germany and The Netherlands. The corrected
29 eco-efficiency using Purchasing Power Parity is less contrasted with respectively 18,
30 3, 3, 4 and 3 kg \$⁻¹. Traditional human ecosystem measurements can serve as a basic
31 comparison point, and as a test for dematerialization indicators. The limit of the
32 indicator of eco-efficiency resides in the different degrees of monetization of the

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

37 **Introduction**

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

45 The idea is to tend towards a more efficient and sustainable development: to produce more
46 human well being using less natural resources, i.e. decoupling economic growth from material
47 use. This idea comes from the recognition that there is a material (natural) limit to growth [4-
48 6].

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

52 The Total Material Requirement (TMR) measures the global pressure of primary matter on
53 natural systems by summing the primary matter input expressed in tons, including the
54 ecological rucksacks [9]. A light version of these accounts distinguishes the Direct Material
55 Input (TMR minus hidden flows) and the Total Material Output that includes emissions (in
56 air, water, waste) and goods exports. In omitting hidden flows (thus the impact of imports on
57 material extraction in the rest of the world), this light version is not suitable for deriving
58 sustainability indicators, since an apparent dematerialization could occur in case of
59 dislocating of heavy productions to the rest of the world. However, in an international
60 statistical work, such an approach could be cheaper to conduct, providing the TMR
61 afterwards is calculated by consolidating the results of all trading countries together. The
62 hidden flows are typically associated with extraction activities, harvesting or infrastructure
63 development [1]. Eurostat distinguishes the foreign hidden flows (or indirect flows, associated
64 with import-export of primary matter), and domestic hidden flows (unused extraction) [10].
65 TMR is generally calculated excluding water flows but with biotic material expressed in fresh

66 weight, which is **debatable**. Air flows are often excluded from the TMR indicators, the
67 exclusion of which is also debatable in a context of a problematic atmospheric cycle. The
68 main reason to exclude air and water flows, or at least to present them separately, is that they
69 represent enormous mass flows (one order of magnitude more than other materials)[10].

70

71 The first national studies in developed countries show that, for example in Germany [11],
72 -About 50% of the Direct Material Input comes from outside the country, 50% from domestic
73 environment

74 -The material input is of an abiotic nature, mainly solid (from which there is a non-used part)
75 and about 15% gaseous (mainly O₂, N₂)

76 -About 15% of the input is used to raise the material stock in economy, the remaining part
77 being emitted in the environment (or marginally exported).

78 -These emissions are mainly solid (about 60% land filled waste), gaseous (about 25%, mainly
79 CO₂) and to water (about 10%)

80 -The recycling is small

81

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

89 ***Material and method***

90 We tested the method and indicators for the case of Sarowar (N 20°50'21”, E 73°36'31”), a
91 quasi-autarkical Indian village, situated in the mountains of the State of Gujarat, in the Dangs
92 district, on the road Ahwa-Pimpri-Sarowar-Kalibel-Vyara, 30 km from Ahwa.

93 **The Dangs district is a hilly area with several plateaus ranging from 300 to 700 m of**
94 **altitude[30]. It makes the transition between the Gujarat plain and the Sahyadris Mountains.**
95 **The rock is basaltic (Deccan trap). The mean temperature in Ahwa (549 m) is 24, 9°C and the**
96 **mean rainfall is 2076 mm. The rainy season lasts 5 months (May-September), the dry season**
97 **7 months. According to Köppen’s classification, the climate is of type Aw 7-8 with a**
98 **tendency to Am (monsoon). The hills are covered with a forest of teak (*tectona grandis*) and**

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

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

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

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

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

131 We used previous data that we collected in 1982-1983 [32, 34]. At that time, we intended to
132 describe a rural human ecosystem. We collected data using different methods, from direct

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

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

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

158 **Results**

159 The biotic materials represented the major part of the inputs of the economy as defined by the
160 village Sarowar, its fields and the used part of its natural environment. If we had limited the
161 study to marked exchanges, the flows would have been negligible in this largely autarkic
162 economy. Figure 1 represents the material flows within this ecosystem, expressed in tons of
163 dry matters. We distinguished the subsystem “village” with its kitchen gardens (15 ha), the
164 fields (subsystem “ager”, 239 ha), and the natural and semi-natural areas including the forest
165 and pastures (subsystem “silva+saltus”, 206 ha). The domestic animals (and marginally

166 humans and wild animals) travel from one subsystem to the other and represent the
167 connecting elements. Permanent forest cover and traditional agricultural practices relatively
168 limited erosion. However, with potential alternative management such as deforestation and
169 modern cultural practice, this element could become relevant in a possible future.

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

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

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

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

191 As expected, the autarkical village consumes more primary biotic material per capita (4.1 t
192 DM cap⁻¹ y⁻¹) than the Netherlands (0.4 t DM cap⁻¹ y⁻¹). This is due to a relatively extensive
193 use of luxurious natural resources in contrast with the relatively efficient use of domestic
194 scarce natural resources in a very densely populated country like the Netherlands (470 cap
195 km⁻², against Sarowar 136 cap km⁻²). You can note that, due to the protection status of the
196 Dangs forest, and the prohibition of tree cutting, the natural system was far from over-
197 exploited in Sarowar. Compared with traditional extensive cultivation in equatorial Africa
198 (shifting cultivation), this cultivation system is relatively intensive and efficient. We are thus

199 not comparing a full extensive system with an intensive one, but a “traditional” intensive
200 system with a modern one.

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

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

218 The important use of domestic animals as source of milk, power force and high quality
219 fertilizers explain the major part of the non-energetic material flows identified in Sarowar.
220 The stock variation of the economy is remarkably low in Sarowar ($+0.1 \text{ t cap}^{-1}$) if compared
221 to the Netherlands ($+5.0 \text{ cap}^{-1}$).

222 ***Discussion***

223 The literature on material flow accounting tends to concentrate on solid and product flows,
224 expressed in total absolute weight. We are far from traditional human ecosystem studies,
225 which quantify many possible flows. This choice is driven by the policy-oriented nature of
226 material flow analysis: limiting the analysis to the impacts of the economy (i.e. human
227 activities). The further limitation to non-air and non-water flows is driven by pragmatism: it is
228 cheaper to exclude many flows in a first analysis. Moreover, on a national scale, solid or
229 product flows are easier to estimate from existing trade and production statistics. Air and
230 water flows are of a greater magnitude and their exclusion helps to focus attention on more
231 “qualitative” material flows included in solids and products. **However, the qualitative aspect**

232 is certainly not addressed in solid and product material flows, which remain dominated by, for
233 example, inert materials from construction. Qualitative material flows are of greater
234 importance for the environment. For example, flows of toxic compounds can have greater
235 environmental or health impacts than big amounts of stones or grounds. From this point of
236 view, we think that air and water should not be excluded from (even quantitative) material
237 flow analysis or “social metabolism” studies. The transportation of pollutants in air or water is
238 certainly more relevant from the health or environmental perspective than the transportation
239 (by economy) in solid forms. If material flow analysis could help as a first approach to the
240 impact of economy on the ecosystem, therefore we think that air and water flows should not
241 be excluded. Human perturbation of water and atmospheric cycles are two of the major global
242 problems today [36, 37].

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

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

259 The total material flow (TMR) per capita measures the efficiency of the contribution of the
260 population to its economy. This is certainly the most relevant indicator if we want to compare
261 a market economy (a “developed” country) with an autarkical village whose economy is only
262 marginally monetized. TMR could also be divided by hectares or by gross domestic product.
263 For further discussion, let us use here the same metric for TMR as in reference studies
264 (excluding air and water, including hidden flows) in order to be able to discuss the most
265 popular eco-efficiency indicators. The TMR per capita per year was 5 t cap⁻¹ y⁻¹ in Sarowar,

266 against respectively 84, 46, 86 and 84 t cap⁻¹ y⁻¹ in USA, Japan, Germany and Netherlands
267 (table 3). The intensity of material requirement per surface is only 7 t ha⁻¹ for Sarowar, against
268 respectively 22, 151, 189 and 307 t ha⁻¹ for the developed countries considered. Note that for
269 Sarowar, this amount is of the same order of magnitude as the potential net primary
270 productivity of the agro-ecosystem, as measured in an associated culture of sorghum, beans
271 (*dolichos lablab*), maize and fibre plants in a kitchen garden (7.1 t ha⁻¹). In developed
272 countries, the larger amount can be explained by a potentially quicker turnover of non-biotic
273 material flows.

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

294 Given the assumption that GDP does not represent the reality of the economy (in terms of
295 providing goods and services for human well-being), neither in autarkical villages, nor in
296 modern economies, a suitable solution could be to use an adjusted GDP, as a denominator to
297 calculate the material intensity. This adjusted GDP [49-53] would for example exclude
298 defensive expenditures (which is important for developing countries) and include a
299 monetization of autarkic work. For example, in the works on adjusted GDP, the monetization

300 of household labour is taken considering local rates for housekeepers. Since rates for
301 housekeepers are not comparable between countries, this would introduce another type of
302 bias. In order to give comparable results between countries, a hypothetical adjusted GDP
303 would, in turn, need to be calculated in PPP. We do not enter into the debate on adjusted
304 GDPs here.

305 The calculation in this study shows the limits of the economic efficiency concept applied to
306 non-market economies. Moreover, even market economies include significant non-market
307 economic flows [49-54]. Here we can directly question the global relevance of the concept of
308 dematerialization of the economy as expressed by TMR/GDP. Following this indicator,
309 developed countries would be, by far, in advance, regarding dematerialization, even if they
310 remain the biggest users of materials from a global (absolute data) and relative (per capita)
311 point of view. We have seen (table 3) that per capita, the tribes of Sarowar use about 10-16
312 times less material than the mean Occidental inhabitant, and even 5-10 times less if only
313 direct input (grand total commodities) is taken into account. We show in the last row of table
314 3 a possible wrong comparison of apparent intensity of air used (related to intensity of carbon
315 emission), where Sarowar seems 100 times more air-intensive than developed countries. The
316 apparent air use (thus the CO₂ emissions) per capita is of the same magnitude than the per
317 capita use (or emissions) of industrial economies. The difference is however qualitative since
318 we have in Sarowar renewable air uses, thus accounting for zero in greenhouse gas
319 accounting. This kind of comparison would be twice wrong: wrong for the numerator
320 (comparing recyclable use to irreversible use) and wrong for the denominator (using GDP as a
321 measure of the economy).

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

327 Acknowledging that the GDP is not a relevant measure of life satisfaction [55], one can
328 suggest using the concept of dematerialization of life satisfaction, of human well being, of
329 human development or of any corrected GDP, in dematerialization studies. Using different
330 dimension, not mixing different indicators in the same ratio, avoids the illusion of perfect
331 substitutability between the economy and the environment. The goal being to reduce the
332 material impact of whatever human ideal, these two indicators (environment and human well-
333 being) should remain in separate dimensions. Examples of multidimensional tools are the

334 multi-criteria analysis [56] or graphic representation where human well-being and ecological
335 well-being are presented side by side like in Prescott Allen [57].

336 **Conclusion**

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

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- 486

487 **Tables**

488 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

489 Sources: authors and [1]

490 Here, the biotic material for The Netherlands is here expressed in dry weight estimating 31%

491 of dry matter in an average of grains and grass production for this country (see table 2)

492 Table 2

493 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

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

495

496 Table 3: Comparison of material flows (excluding air and water) between a traditional

497 autarkical Indian village (1983) and four developed countries (1991).

	USA	Japan	Germany	Netherland	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	

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

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

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

504 Source: authors and [1]

505 **Figures**

506 [Separate file ecosystem4.jpg]

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

508

