MATERIAL FLOWS FROM A SYSTEMATICAL POINT OF VIEW

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SUMMARY : The paper analyzes the material flows between the ecosphere and anthroposphere and inside the antroposphere. The metabolism is described as a complex system of two operators (process and transport). Definitions of boundaries, Calculation methods to judge services and raw materials are presented. Differences between this approach and usual LCA are shown. Dynamical behaviour of the system is shortly discussed.

KEY WORDS : Material Flow, Material Intensity, MIPS, Life Cycle Analysis, Ecosphere, Anthroposphere, Economic and Industrial Metabolism

INTRODUCTORY NOTES

All material flows, energy consumption, area usage and tranport actions induced by mankind will in a local or global framework create changes in the ecosphere today or tomorrow. It is impossible to predict how fast and large these modifications will be. There is also no lower limit of material flow or energy consumption which is riskless. A good example is the unexpected impact of CFCs on the ozone layer of the atmosphere. To be on the safe side the natural system should be impacted as absolutely little as possible. That means - politically speaking - the precautionary principle should be applied always. Man induced material flows, energy consumption, area usage and transports should be as low as possible. In the last centuries human activities have increased the flow of material, the energy consumption, the area usage and the amount of transport to a level that changed the balances of the ecosphere. There will eventually be new balances in the ecosphere, but these new balances might not be favorable for mankind.
Therefore the goal of the next decades is to minimize the impact of mankind on the ecosphere. Reducing the material flow in a proper way will automatically decrease energy consumption, area usage and transport. That means saving our ecosphere is correlated with a decisive reduction of man induced material flows. It is possible to reduce the material intensity of our welfare by a factor of 10 or more in the long run. To distinguish different approaches and to choose the right ones for such a step towards a sustainable economy, we need to have reliable and easy to understand measurements about the amount of material, energy, area, and transport used to realize a product, service machine or service unit **(1)**.

BOUNDARIES, SOURCES, SINKS , OPERATORS - from "cradle" to „grave"

To define such measurements we have to define boundaries between the ecosphere and the anthroposhere or technosphere, between natural flows and man-induced flows. The anthroposphere is a subsystem of the system Earth in which all human activities happen. This subsystem needs inputs from the ecosphere, processes material and energy, induces flows inside the anthroposphere (transports) and produces outputs back to the ecosphere. The system boundaries we will use to achieve our goal must include all man-induced material flows (**2,3**).

On the **input side**, the "cradle" or the "sources" of material flows, the boundaries that are defined by material flows created or changed by all sorts of direct or indirect economic interests and all sorts of technologies used by man. There are principally three "sources" : the natural biological resources where we hunt and collect, the agriculture which means the cultivation on soil, and the geological resources (**see picture Material Flows 1**).
Some examples may clarify this definition. In the case of mining all material touched by machines enter the anthroposphere in the moment they are touched. Even if they are only dislocated by a few meters like overburdens. In the case of agriculture the process of harvesting puts material into the anthroposphere. All water, herbicide, or fertilizer going through the surface of the cultivated soil are part of the anthroposphere. The amount of soil entering the anthroposphere is the soil eroded by the cultivation process.

How to distinguish between areas which are cultivated and areas where hunting and collecting put materials into the anthroposphere ? If man and his activities rule the distribution of the main species on a certain area in a planned manner (like wood production), then this is a cultivated area even if sowing and harvesting are separated by centuries. This means that mostly all woods in Europe are cultivated regions.

On the **ouput side**, the "grave" or the "sinks" of material flow leaving the anthroposphere is defined by the absence of conduction by man made technologies and economic interest. In principle here also exist three „sinks", the litho- and pedosphere, the hydrosphere and the atmosphere. Output into the ecosphere happens at all parts of the metabolism of the anthroposphere, firstly as dissipative losses and secondly as part of technological processes (**see pictures Material Flows 1 and 2**).
Furtheron some examples to clarify this definition: water leaving the pipe or gases leaving the chimney become part of the ecosphere. Materials deposited on an area not more touched anymore by technologies (like the tire thrown into the woods) become part of the ecosphere.

Inside the anthroposphere the materials are physically or chemically changed by "processes". A "**process**" consists of input materials which interact and produce outputs. Inputs are all types of

goods of the anthroposphere, like raw materials, intermediate products, infrastructure and products, and inputs from "sources". The outputs are goods and materials going into „sinks". The processes are connected by „transports". Each „**transport**" starts at a given point with a given transport system and ends at another point. It has a distance which for systematically reasons may also be zero (two processes at the same location). The „transport" needs also some input materials, like fuel and the transport system, and produces outputs to the „sinks". These **two operators** („process" and „transport") are able to describe the whole metabolism of the anthroposphere. Describing the anthroposphere with these two operators leeds us to a complex picture with deeply inter-connected operators.

From a systematical point of view there is no diferrence between the flow of money, the input of an amount of work done by man, the allocation of area or material flow, all these may serve as inputs and outputs for the operator „process". To describe the flows of capital inside the anthroposphere it is possible to link all „processes" also with the antrospheric material money (money has no „source" or „sink" in the ecosphere). A Projection of this ideas into a Database is the „CAMA" Software designed at our Institute (**4**).

Measurements - MIPS et. al.

With these definitions we will define some measurements. First we need to calculate „**MIPS**", the material input / intensity per service machine (e.g. television set) or service unit (e.g. one kilowatt electricity or one kilometer transportation). To do so we only have to add all „sources" needed to produce this service machine or unit. All „sources" includes the „sources" upstream and „sources" involved by processes downstream (e.g. the material needed to repair or dispose) and the „sources" involved by processes sidestream (e.g. sources needed for goods which are involved at any process stage). All „sources" includes also the processes needed to maintain the infrastructure. This sum is a value for the induced material flows of a product. This number can also be calculated for a **region** (accounting imports and exports) and indicates the material consumption of a region. Dividing this number with a value for the welfare of a region (e.g. GNP) one can easily compute the **material productivity** of that region.

Designing new products one has to compare different intermediate or raw materials (eg. aluminium, steel, plastic, wood) and decide which one is more environmental. Provided that both fulfill the technical conditions, the rucksack of material input through „sources" from the ecosphere until their production is a method to choose the right material („**MIM**" material input / intensity per material unit). In this case only the upstream and sidestream processes and transports involved till the point where the material is used are calculated. Since you can't predict what material intensity is induced by using, repairing and the disposal of the good built with the material you have choosen, downstream processes can't be counted. This measurement

is very dangerous, for example : building window frames out of wood or plastic will lead to the decision to use wood from the region, it has a less rucksack of material than plastic. This wood frame may need a lot more of maintenance than the plastic frame, under certain circumstances this maintenance has a much bigger rucksack than that of the plastic material.

Having analyzed all the material flows involved with one service machine or unit you are also able to calculate subsets like certain metals or energy carriers. Completely analogue to the definitions above are the definitions of **material output** per service machine / unit and the definition of material output per unit material. In this case you add the „sinks“ instead the „sources“. The difference between the material input and output for a region in a certain time is the amount of **frozen mass** into the infrastructure and long living products. Summing up all involved transport distances for a good gives the amount of induced transport. This measurement is a value for the internal **handling velocity** of the anthroposphere.
What is the difference between classical LCA methods and this approach? Firstly the analysis works on a much broader frame with clearly defined boundaries and operators, secondly it includes all material flows, it does not distinguish between toxic and non toxic materials, thirdly it allows linkage of money flow or other flows with the material flows and last but not least if stored in a database the calculation of different types of measuremets. With the database you can calculate the „rucksacks“ of material input carried by goods. This value is a fast way to judge new and old products.

To achieve our goal of reducing the subsystem anthroposphere has to be changed in the right way. To distinguish between the different szenarios towards a less material intensiv economy we have to use the measurments defined above and study the **dynamical behaviour** of the subsystem anthroposphere. The anthroposphere has to reduce its material intensity („sources“), the frozen material in infrastructures, the amount of area and energy used and to „cool“ down, which means to reduce the handling velocity of the metabolism. Reducing all this means that for a certain time the output of materials will increase („sinks“) and a new balance of inputs, processes, transports, and outputs at a lower level will establish.
Further studies about this dynamical behaviour of the anthroposphere, maybe under consideration of entropy production inside the anthroposphere will be done.

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