Allocation - an Issue of Valuation ?

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1. Overview

Within the field of allocation problems in LCI a distinction between simultaneousness (multi-output- and multi-input-processes) and succession (multi-use or open- and closed-loop-recycling) should be made. The former occurs while dealing with single processes, a factory or a region, the latter is also typical for whole life-cycles of products (or functional units). Before the task of how allocating energy- and material-flows can be dealt with one has to answer the question if the process at issue is a multi-output-process or not, if it is a recycling-process or not. Therefore, the two steps are treated separately in this paper.

For a coherent treatment of energy- and material-flows a distinction between outputs (recycled or downcycled materials) and inputs (primary or secondary materials) is made. While the former are outputs of processes during or at the end of a life-cycle, the latter are inputs at the beginning or within a life-cycle of a functional unit. The discussion in the paper covers the questions how to class the outputs of a process or a life-cycle (co- or by-products, re- or downcycling) and how to allocate energy- and material-flows as well as physical, chemical and biological properties to the outputs. Fig. 1 shows an overview of allocation problems with the different stages and possibilities of allocating energy- and material-flows.

The terms used in this paper are described in Chapter 5. "Glossary of terms".

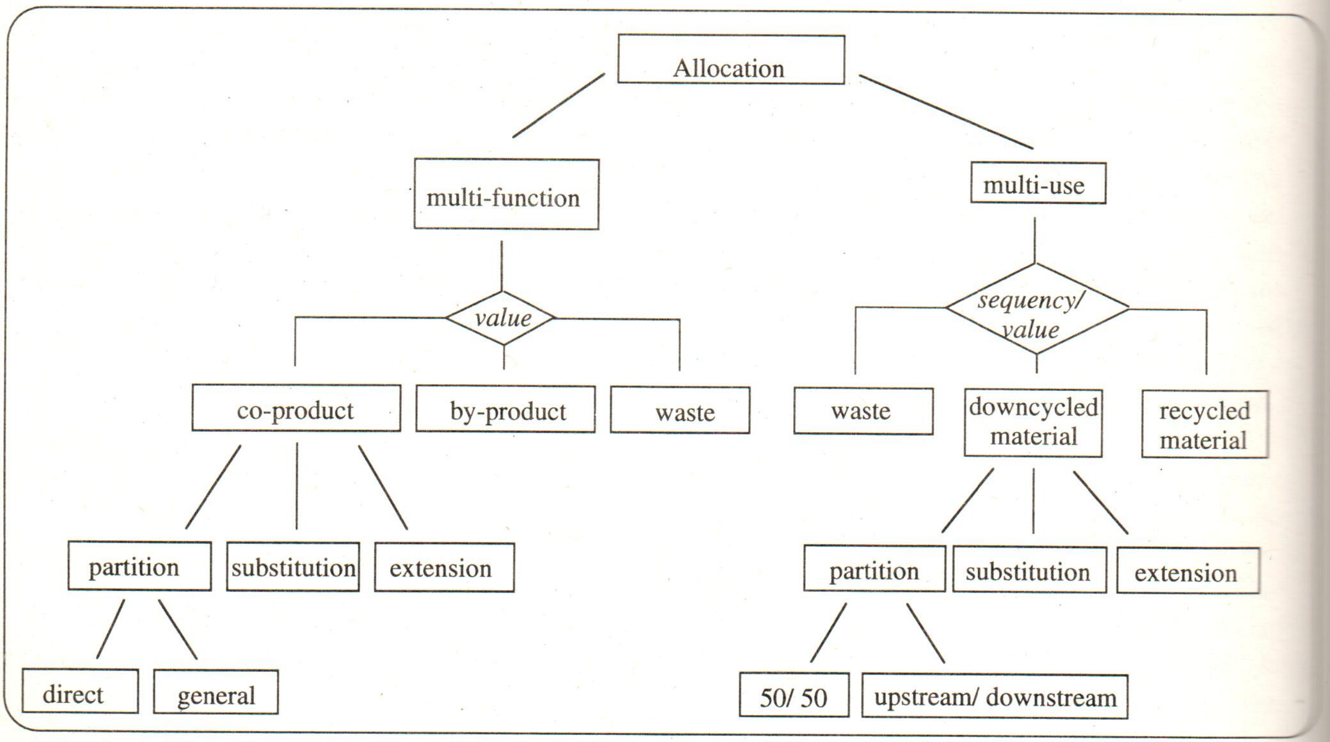

Fig. 1: Overview of allocation problems (Definition of terms see chapter 5)
decision criterias (see also chapters 2.1, 2.2 and 3.2):
- value: economic value based on an economy with internalized externalities
- sequency: succession of materials or energy with decreasing level of quality

2. Allocation, yes or no

2.1 Multi-output-processes

2.1.1 Methodology

Nearly every process is a multi-output-process. Beside of the intended product, emissions to air and water as well as wastes are produced. So the question arises how to define or locate the border between emissions or waste and products, between the useless (or even harmful) and the useful output. There are several possibilities to decide about the usefulness of an output.

In <SETAC 1993> the key-words are "'beneficial use' for other systems". Most common is the use of "economic values" of the output <Heijungs et al. 1993, Braunschweig et al. 1993>. A positive economic value indicates that there is a demand for the output in question. Products with a negative economic value can be seen as wastes. <Braunschweig et al. 1993> even go further and state that a product with positive economic value but a greater environmental impact (assessed with the valuation method of critical loads <Ahbe et al. 1990>) than a product made out of virgin material has to be considered as a waste. Here the influence of a valuation becomes obvious.

But also using the "economic value"-criteria is an implicit valuation. The prices of products and services in social economies are influenced by their legal, social and physical (natural capital) conditions. Economies with little or no internalized externalities may favor the purchase of environmentally harmful products if comparative advantages on environmentally friendly products are achieved due to unpaid externalities. Therefore markets may exist for products or services which would not exist or which would be smaller if all externalities are internalized. This means that the economic value for such products would change from positive to negative or at least would decrease.

Therefore using the economic value for the decision if outputs are co-products (see chapter 5. for description) or not implies a valuation done up to now without (or nearly without) considering environmental external costs. But doing this eventually excludes considerations from the allocation process which might be essential for the final aim of sustainability.

This leads to the conclusion that, with sustainability as one scope of a LCA (see for example <Karlsson 1994>) and using economic values for the decision if an allocation-problem exists or not, this should not be done *without considering the effects on the economy and its material- and energy-flows caused by internalized externalities*. Of course this statement is only important for allocation problems with a decisive effect on the overall-results of the LCA of a product.

Furthermore the following context should be considered. Sometimes it is argue that small (incremental) steps towards sustainability still are sufficient. But it may happen (and the contrary has not yet been proven) that today's market situation and therefore today's allocation criterias are impeding any step at all. It has been shown in <Frischknecht et al. 1994> that 40, 55 and 65 % of total emissions of NO_X, SO_2 and CO_2 respectively allocated to the electricity production by photovoltaic cells stem from the electricity (UCPTE-mix) used for the fabrication of solar cells. It would therefore be wrong to hinder the longterm development of photovoltaics on the basis of today's situation in electricity production. These deep changes in system properties necessary for real sustainability imply inevitably a strong nonlinear character of the whole system. Therefore additional informations and scenarios are needed when aiming at a longterm sustainable energy policy.

Because of the fact that a LCI may need values of today's economy for deciding about changes towards sustainability in the same economy (feedback-loop) it is nessessary to iteratively calculate the product system in cause. As external costs are hardly available and a simulation of market-situations in an economy on the basis of internalized externalities has not been done with the detailedness required another approach has to be followed.

It is therefore proposed to define the function of the process in question This may take place on the level of a plant (e.g. a refinery) or on a more detailed level of subsystems (e.g. atmospheric destillation, isomerisation process etc.). With such a definition, the outputs are implicitely classified as co-products (allocation needed, see chapter 5.) and by-products (no allocation). Of course there is a need for agreement among different actors (producers, analysts, officials etc.) for the purpose of an overall balance of energy- and material-flows among the LCA's of different product systems.

2.1.2 Examples

The following examples serve on one hand to clarify the problem of using today's economy for the decisions on allocation and on the other hand to show possible procedures when defining the function of a process.

- economic values

The use of slag as building material (road foundation) is economically feasable (cheaper than using virgin gravel) and therefore has a positive economic value on the market. Investigations on the behaviour of the slag as foundation material show on the other hand that, from the point of view of groundwater contamination, controlled disposal is the better solution <Belevi et al. 1992>. Hence, despite of the positive economic value, slags in foundations induce additional environmental impacts in the field of water contamination. On the other hand slags lead to a reduction of environmental impacts due to resource savings.

Rotary kilns for cement production use used tyres as energy source replacing coal and waste oil. Carriers have to pay for the disposal of tyres if dumped and the cement factory has to pay for the coal used. So the marginal costs of used tyres may be negative or positive depending on the point of view or the present market situation.

- Definition of processes

The purpose of defining a process or a system lies in the implicitely settled categorisation of the different outputs. With such a definition outputs are classified as co- or by-products or waste respectively with (co-product) or without (by-product, waste) their share on energy- and material-flows. Doing so the discussion of allocating impacts to the different outputs is done on the system-level which helps avoiding incoherent treatments of outputs. Of course it is still possible to have different definitions of the function of a system and therefore an incoherence in allocating impacts to outputs in different product systems. But a discussion and possible agreement on a function of a process- or system is easier to be carried out and punctual views suiting a particular solution (not nessessarily the problem) will rarely be choosen.

As examples the processes "waste incineration" and "refinery" are defined on a plant level.

A waste incineration plant can be defined as a process which:

- treats wastes,
- treats wastes and produces electricity and heat,
- treats wastes and produces electricity, heat and building materials,
- treats wastes and produces electricity, heat, building materials and brine,
- etc.

An oil-refinery can be seen as a process which produces

- oil products,
- oil products and sulphur,
- oil products and electricity,
- oil products, sulphur and electricity.

Using the first definition of a waste incineration plant, only treated wastes are products; energy, slags and brine are by-products. The second definition includes energy as a co-product whereas the third considers even slags as a co-product etc. Market prices may be a help in defining the function of a process. Looking at costs and proceeds of a waste incineration plant it is obvious which of the outputs dominate the balance (see Tab. 1).

As a rule of thumb one could consider only these products as co-products whose proceeds exceed one tenth of the percentage of proceeds of the dominant product (> 7 % in the example in Tab. 1). This procedure works on the level of general allocation because all outputs seem to be produced simultanously. In <Ménard 1994> the example of a waste incineration plant is discussed more in detail.

[%]	Proceeds	[%]	Costs
Garbage Fees	70	Capital	50
Waste heat Selling	15	Staff	10
Electricity Selling	10	Repair & Maintenance	20
Building Material	1 1)	Auxiliary Materials	3
Sulfur	1 1)	Disposal of Waste	5 - 10 1)
Gypsum	1 1)		
Brine	1 1)		
Total	100	Total	100

Tab. 1: Hypothetical economic balance of a waste incineration plant; 1): proceeds of selling < costs for treatment but proceeds of selling minus costs of treatment >> costs of disposal

Looking at a refinery as a black-box system, the question arises if the sulphur recovered is a co-product. The quality of the product is about the same as that of primary sulphur and the economic value of sulfur is positive although the alternatives for the refinery are to sell or to dispose of (paying a fee).

The purchase of crude oil and the production of oil products is mainly influenced by the economically optimal portfolio of oil products. For example heavy crude oils (normally with a high sulphur content) are bought for the production of bitumen <Raffoil 1993> and not for an extension of sulphur production. Therefore it can be argued that despite of the positive economic value of sulphur, which again reflects current market situation without internalising externalities, sulphur should be handled as a by-product. This is in coincidence with the purpose (function) of a refinery *namely producing marketable oil products*.

2.2 Recycling

The problem of locating the border between downcycling and waste treatment is similar to the situation for multi-output-processes. The same conclusions about economic values as above can be stated. Additionally the question arises if the multi-use materials or products are in an imperative sequence or not. If the latter is the case (e.g. closed-loop-recycling) there is either no allocation problem (only one system has to be analysed) or it has to be treated like open-loop-recycling. If the succession is absolute (open-loop-recycling) there is a need for an allocation criteria differing from the one used in multi-output-processes.

3. Allocation procedures

If the answer to the question about the existence of an allocation problem is affirmative, an adequate criterion has to be found. This means - as it is done when designing the process-tree - to model the real system considering the causality, the motivation why a process is run and which products are purchased.

The possibilities of allocation-methods are shown in Fig. 2. The first step is to separate all processes, material- and energy-flows that can be allocated based on functional, physical, chemical or technical causalities (see also <Huppes 1994>). Because step one in <Huppes 1994> can be seen as an allocation of *processes*, the term "direct partition" for allocation due to functional, physical, chemical or technical causalities is used. General partition on the other hand leads to an allocation of energy- and material-flows to the different co-products by an allocation key to be determined (e.g. mass, energy or exergy content, concentration, molecules, prices etc.).

	1	2
Partition (direct)	X	X
Partition (general)	X	▨
Substitution (Scenarios)		X
Extension	X	X

Fig. 2: Possible allocation methods and their use, 1: same physical units, 2: different physical units; For description of terms see chapter 5. "Glossary of terms"

When allocation is done by substitution, energy- and material-flows caused by the main process are related to the central co-product and the energy- and material-flows of alternative single-output-processes producing the other co-products are subtracted. As several possibilities for single-output-processes exist, defining scenarios is inevitable. E.g. in <Braunschweig et al. 1993> it is argued that the waste heat of an incineration plant recovered for domestic heating purposes saves the emissions caused by a modern gasfired heating system delivering the same amount of energy. It is stated therefore that the emissions of the gas furnace should be subtracted from the emissions of the incineration plant. For consistency reasons all upstream emissions should also be subtracted and on the other hand for the reason of an overall-balance waste heat used for heating purposes should be charged with the life-cycle emissions of the same gasfired heating system.

Opposite to the substitution method, the extension method aims at enlarging the system to the point where no more allocation has to be carried out and where each one of the different systems to be compared covers the same funcional units (smallest common multiple, see e.g. <Schneider 1994>). Energy- and material-flows of additional processes are added to the one at issue. Also here several possibilities exist and therefore scenarios have to be defined. Following this procedure consequently, nearly all economic activities have to be analysed because of the strong interactions in the worlds economy.

Until now partition is mostly used when the physical units of the outputs are the same (mass, molecules, kWh etc.). If not, e.g. when heat recovery is practised, a substitution theory or the extension theory often are applied <Braunschweig et al. 1993, Heintz et al. 1992>. Nevertheless it should be aimed at a partition of energy- and material-flows even in the case of different physical units. This can be achieved by a) breaking the system into subsystems (direct partition, see the next chapter, <Knoepfel 1994> and <Ménard 1994>) or b) by using conventions, where the valuation is obvious and transparent. Converting the different units to one common unit by using prices of todays economy should only be used for studies with incremental impact on the economy as a whole or with neglectable influence on the results of the LCA carried out because of the reasons listed in the previous chapter.

3.1 Multi-output-processes

Allocation-problems of systems (processes or plants) may occur at different levels of detailedness. As they can be avoided at least partly by dividing the system into subsystems with single outputs and definite causality, a separation should be attempted to represent better the causality of the energy- and material-flows (see also <Huppes 1994, van der Ven 1994, Rønning 1994, Finnveden 1994>).

Within the oilfuel-cycle the refinery is the key-process regarding energy consumption in the upstream activities. Looking at a refinery as a highly aggregated black-box and using different allocation criterias for energy- and material-flows, the following coefficients result:

	allocation coefficients				
	Mass	Heating Value	Price 1)		
			1974	1984	1992
Gasoline	1	1.02	1.21	1.11	1.20
Gas Oil	1	1.01	0.97	1.03	1.10
Heavy Fuel Oil	1	0.95	0.81	0.79	0.52
average of refinery	1	1	1	1	1

Tab. 2: Allocation coefficients of selected refinery-outputs according to different allocation criterias, 1): Rotterdam spot market <BP 1993>

There is practically no difference between mass and heating-value allocation, whereas the differences between the allocation based on the prices of different years are significant as the importance of heavy fuel oil on the world market decreased substancially. The difference between mass- and price-allocation lies between + 20 and - 50 %. Using the detailed energy- and massflows of a european refinery <Frischknecht et al. 1994> a more adequate allocation (closer to physical or chemical reality) for energy-use and related airborne-emissions and crude-oil demand, catalyst requirements and emissions to water has been performed. As the subprocesses like destillation, desulphurization etc. still are multi-output-processes, an allocation criterion has to be used (general partition of the 2nd order). Because of hardly available prices (even of todays economy) for semifinished products and unknown heating values, the mass remained the only operable and therefore used criterion.

The results can be summarized as follows:

	CH 1991 [%]	Catalysts (Matrix)	thermal Energy	Electricity	Emissions to water
Gasoline	28	2.1	2.0	1.5	1.0 - 1.2
Gas Oil	50	0.4	0.5	0.5	1.0 - 1.2
Heavy Fuel Oil	22	1.1	1.0	1.0	0.3 - 1.7
average of refinery	100	1	1	1	1

Tab. 3: Product-portfolio of Swiss refineries output 1991 <Frischknecht et al. 1994> and relative importance of selected refinery outputs based on a detailed analysis <Frischknecht et al. 1994>; allocation based on mass for multi-output-subsystems

It shows that gasolines require much more catalysts and precious metals than less sophisticated products. Also thermal energy and electricity used within refinery are higher for gasoline by a factor of 4 and 3 respectively compared to gas oil. Because of its reduced demand of heavy fuel oil on one hand, the rather intensive cotreatment of heavy fuel oil in various subprocesses of the refinery on the other, economic and physical values differ quite markedly.

When the product portfolio of the refinery is changed in the direction of an increased amount of light products (whitening of the barrel), the relations as well as the average amount of energy used within refinery will change dramatically as is shown in Tab. 4. The average energy used within refinery increases by a factor of 2 compared to the refinery considered in Tab. 3.

	US 1991 [%]	thermal Energy
Gasoline	53	2.5
Gas Oil	33	1.5
Heavy Fuel Oil	14	1.0
average of refinery	100	2 $^{1)}$

Tab. 4: Product-portfolio of US-american refineries output 1991 and allocation criterias of selected refinery-outputs based on a detailed analysis <Frischknecht et al. 1994>, $^{1)}$: 1 = average of Swiss refineries 1991 (Tab. 2)

3.2 Allocation for Open-Loop Recycling

When certain energy- or material-flows are crossing the border between two or more systems, an allocation criterion according to the four categories mentioned in Fig. 2 has to be selected. As the imperative sequency of the processes linked together is used as a criterion for open-loop recycling (down-cycling), the causality of the connected processes is given. Generally it can be stated that a process would also be pursued if process(es) in sequence would be inexistent. Initially, waste incineration plants were built to reduce the volume of waste by thermal treatment and not because of substituting recovered heat for fossil fuels or slags for virging gravel in road construction activities. The commercialization of such outputs mainly is an effect of scarcity of the products substituted for caused by growing economic activities. But when scarcity of the resources used for a product has an impact on its economic value, the depletion of resources may already irreparably have happend. Therefore upstream activities should be allocated to the process using virgin and offering downcycled materials (or energy) and processing and transportation of the recovered material or energy to the process using secondary raw materials or waste heat (see also <Frischknecht 1992>). The first process benefits because it produces less waste (or waste heat) whereas the second may benefit in reduced resource-consumption and/ or in reduced emissions.

Like it is done in the case of multi-output processes, direct allocation due to functional, physical, chemical or technical causalities should be achieved when analysing multi-use systems because of a distinction between material- and process-related emissions (see <van der Ven 1994>). How to deal with physical, chemical and biological properties of products which may lead to material-related emissions to be allocated directly will be shown in the next paragraph.

As a special case of open-loop recycling heat-recovery crossing the border of the system at issue is considered. Using waste heat, the waste heat emissions and the use of primary energy resources are reduced. According to the allocation procedure stated above, the process, which *leads* to heat recovery by others, has less waste heat releases whereas the process *using* waste heat is charged with the impacts of recovering and transportation of the waste heat.

3.3 Heredity of physical, chemical and biological properties

Beside the question of allocating energy- and material-flows caused during upstream processes to co-products and by-products the problem of how to allocate physical, chemical and biological properties and their impacts has to be solved. In <Fecker 1990> for example a bonus is given for re- and down-cycled materials with a heating value. For consistency reasons at least the released emissions due to burning the material should also be related to the life-cycle where the re- or downcycled material stems from. As this approach is a relic from the time of energy analysis, another method is proposed here. The properties of products like free enthalpy, carbon and trace element content etc. are transmitted to the following process-chain using these products.

A special consideration is needed when the materials stem from renewable resources because they extract energy and chemical elements from the biosphere (e.g. sawchips used for heating purposes). As wood extracts CO_2 and energy from the air, Nitrogen and trace elements mainly from the ground, it is charged with negative CO_2- and waste-heat-emissions and so on. As these properties are not touched in the sawmill, they are transmitted to the by-product "sawchips". If not, the sawmill would be encouraged to produce more sawing-wastes for lowering its CO_2-emissions and other impacts charged on its product "sawed wood".

4. Conclusions and outlook

- When talking about allocation it is important to differenciate between multi-output and multi-use, because the procedure of answering the question whether an allocation problem exists or not is different as well as the allocation procedure itself.

- When one scope of a LCA is a (non-incremental and therefore nonlinear) change towards sustainability, monetarized values of outputs both of processes and life-cycles may lead to wrong conclusions concerning the classification of outputs (e.g. co- or by-product, waste) and to wrong allocation of environmental burdens because the allocation would then be based on todays economy and their implicite *valuation criteria*. As in today's economy natural capital (still) is a free good, another valuation scheme should be choosen. Otherwise LCA might loose its purpose of showing a way towards sustainability. A first approach for a more adequate allocation is to define the function of a process, which implicitely defines the different outputs as co- or byproducts or waste respectively. This definition for a number of basic processes (e.g. municipal waste incineration) can be settled by a panel of scientists, government officials, industrialists, NGO's etc. (as one possibility).

- General allocation (based e.g. on mass or energy content only) may lead to allocations differing substantially from allocation procedures considering functional, physical, chemical or technical causalities. Therefore the latter should be preferred although general allocation cannot be avoided totally.

- Incorporated physical, chemical and biological properties should be transmitted with the material-flows crossing the system boundaries. Negative emissions due to extraction of environmental goods like energy, CO_2 etc. by renewable resources like wood should be allocated to the life-cycle setting free these properties.

- In a next step within the activities of the Energy - Materials - Environment Unit, a first estimation of possible influences of substituting values based on an economy with internalized externalities for todays economic values for allocation problems will be carried out. These considerations are embedded in the project "Datenpflege" funded by the Federal Department of Energy (BEW) and the project- and studies-fund of the Swiss association of power supply companies (PSEL).

5. Glossary of terms

The terms listed below differ partly from the ones used in <SETAC 1993> mainly because of clarifying purposes. As far as possible a reference to the terminology in <SETAC 1993> is given. Th use of some of the terms listed below is shown in an example in Fig. 3.

- By-product:

By-products are outputs of a process (or a plant) without satisfying part of the function of the process at issue (e.g. waste heat of lighting). By-products are used as secondary raw materials or -energies on a lower level of quality and /or order (imperative sequency).

- Co-products:

Co-products are outputs of a process (or a plant) which are intended by definition of its function. Unlike processes with a single output, several functions are satisfied by the process (e.g. cogeneration, oil-refinery etc.).

- Waste:

Wastes are solid, liquid or gaseous products out of a process which need further treatment like incineration, sewage treatment, disposal of frozen CO_2 in deep ocean etc. The impacts (emissions to air and water and immobilized solid materials) resulting from these activities are related to the life-cycle of the functional unit in question.

- Recycled material:

Recycled materials are goods or materials which are used as secondary raw materials for the production of the same or qualitatively equal goods or materials. During their life-cycles they do not suffer irrevocable quality reductions (closed-loop-recycling).

- Downcycled material:

Downcycled materials are goods and materials which are used as secondary raw materials for the production of qualitatively minor goods. During their life-cycle they suffer irrevocable quality reduction which results in imperative sequency of the use of the material (open-loop-recycling).

- Downcycled energy:

Recovered waste heat is called downcycled energy. The energy is used on a higher level of entropy and therefore an imperative sequency of the systems connected by this energy-flow is given.

- Secondary raw material:

Secondary raw materials are collected and refined used goods (products at the end of their life-cycle, post-consumer-goods) and collected and refined wastes of production induced by the technology used (by-products on each step in the life-cycle, pre-consumer-goods). They are inputs to following life-cycles and may stem from closed- or open-loop-recycling.

- General partition:

A partition is called general when energy- and material-flows are allocated by a common criteria to be determined (e.g. mass, energy or exergy content, concentration, prices) partly without considering functional, physical, chemical or biological causalities (or realities) for differentiation.

- Direct partition:

A partition is called direct when processes, energy- and material-flows (incl. properties) are allocated by breaking up the system in subsystems which allows to consider functional, physical, chemical or biological causalities.

- Substitution:

When allocation is done by substitution, energy- and material-flows caused by the main process are related to the central co-product and the energy- and material-flows of alternative single-output-processes producing the other co-products are subtracted. As several possibilities for single-output-processes exist, defining scenarios is inevitable.

- Extension:

The systems to be compared are enlarged by additional processes up to the point where each one covers the same funcional units (smallest common multiple). Energy- and material-flows of additional processes are added to the one at issue. Also here several possibilities exist and therefore scenarios have to be defined.

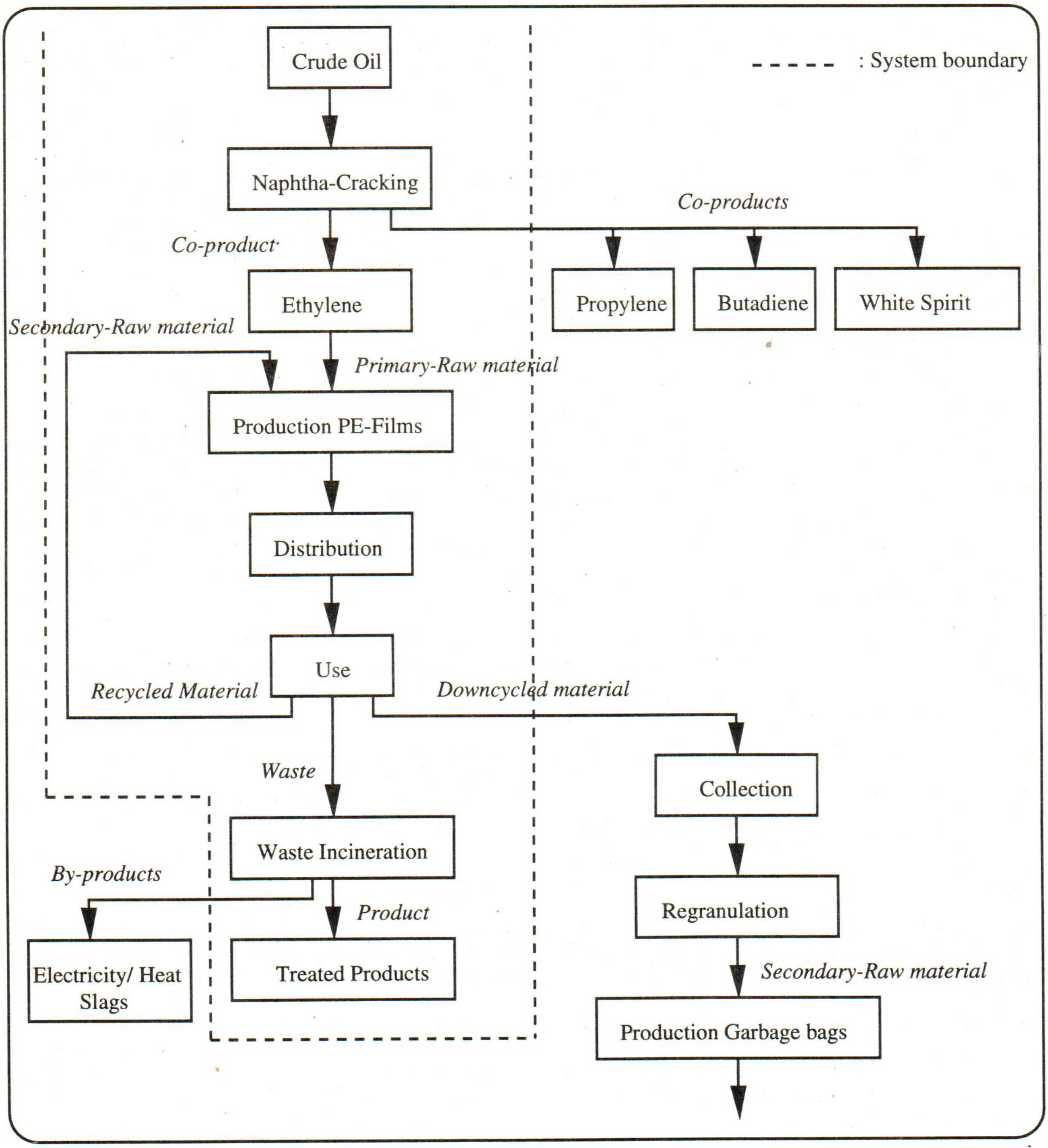

Fig. 3: Terms in connection with allocation problems showed on the example "PE-films in agriculture an their further use" <Frischknecht 1992>

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