TECHNICAL REPORT

ISO/TR 14049

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Environmental management — Life cycle assessment — Examples of application of ISO 14041 to goal and scope definition and inventory analysis

Management environnemental — Analyse du cycle de vie — Exemples d'application de l'ISO 14041 traitant de la définition de l'objectif et du champ d'étude et analyse de l'inventaire

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

In exceptional circumstances, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example), it may decide by a simple majority vote of its participating members to publish a Technical Report. A Technical Report is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

ISO/TR 14049 was prepared by Technical Committee ISO/TC 207, *Environmental management*, Subcommittee SC 5, *Life cycle assessment.*

Introduction

The heightened awareness of the importance of environmental protection, and the possible impacts associated with products manufactured and consumed, has increased the interest in the development of methods to better comprehend and reduce these impacts. One of the techniques being developed for this purpose is Life Cycle Assessment (LCA). To facilitate a harmonized approach, a family of standards on life cycle assessment (LCA), including ISO 14040, ISO 14041, ISO 14042 and ISO 14043 and this document are being developed by ISO. These International Standards describe principles of conducting and reporting LCA studies with certain minimal requirements.

This Technical Report provides supplemental information to the International Standard, ISO 14041, *Environmental management - Life cycle assessment - Goal and scope definition and life cycle inventory analysis*, based on several examples on key areas of the Standard in order to enhance the understanding of the requirements of the standard.

Methodological requirements for conducting LCA studies are provided in the following International Standards concerning the various phases of LCA:

— ISO 14040: *Environmental management - Life cycle assessment - Principles and framework.*

— ISO 14041: *Environmental management - Life cycle assessment - Goal and scope definition and inventory analysis.*

— ISO 14042: *Environmental management - Life cycle assessment - Life cycle impact assessment*.

— ISO 14043: *Environmental management - Life cycle assessment - Life cycle interpretation*.

Environmental management — Life cycle assessment — Examples of application of ISO 14041 to goal and scope definition and inventory analysis

1 Scope

This Technical Report provides examples about practices in carrying out an Life Cycle Inventory analysis (LCI) as a means of satisfying certain provisions of ISO 14041. These examples are only a sample of the possible cases satisfying the provisions of the standard. They should be read as offering “a way” or “ways” rather than the “unique way” of applying the standard. Also they reflect only certain portions of an LCI study.

It should be noted that the examples presented in this Technical Report are not exclusive and that many other examples exist to illustrate the methodological issues described. The examples are only portions of a complete LCI study.

2 Technical Introduction

The examples focus on six key areas of ISO 14041 as indicated in Table 1.

In some key areas there is more than one example. The reason is that in many cases more than one practice exists. The decision about the application of one or the other practices is goal dependent and can vary e.g. from the product system under investigation or in the stages over the life cycle. The examples are described in the context of the corresponding provisions of the standard and with the specific use.

In the description of the different cases, whenever possible, the following structure has been adopted :

– Context of the standard

– Overview

– Description of the examples

Table 1 – Cross references between ISO 14041 and examples in this document

ISO 14041	Examples in ISO/TR 14049
0 Introduction 1 Scope 2 Normative reference 3 Terms and definitions 4 LCI components 4.1 General 4.2 Product system 4.3 Unit process 4.4 Data categories 4.5 Modelling product systems 5 Definition of goal and scope 5.1 General 5.2 Goal of the study 5.3 Scope of the study 5.3.1 General	
5.3.2 Function, functional unit and reference flow	3 Examples of developing functions, functional units and reference flows 4 Examples of distinguishing functions of comparative systems
5.3.3 Initial system boundaries 5.3.4 description of data categories	
5.3.5 Criteria for initial inclusion of inputs and outputs	5 Examples of establishing the inputs, outputs and boundary of unit process 10 Examples of performing sensitivity analysis
5.3.6 Data quality requirements	9 Examples of conducting data quality assessment
5.3.7 Critical review 6 Inventory analysis 6.1 General 6.2 Preparing for data collection	
6.3 Data collection	9 Examples of conducting data quality assessment
6.4 Calculation procedures 6.4.1 General	
6.4.2 Validation of data	9 Examples of conducting data quality assessment
6.4.3 Relating data to the unit process	
6.4.4 Relating data to functional unit and data aggregation	3 Examples of developing functions, functional units and reference flows
6.4.5 Refining the system boundaries	10 Examples of performing sensitivity analysis
6.5 Allocation of flows and releases 6.5.1 General	
6.5.2 Allocation principles	6 Examples of avoiding allocation
6.5.3 Allocation procedure	6 Examples of avoiding allocation 7 Examples of applying allocation
6.5.4 Allocation procedures for reuse and recycling	8 Examples of applying allocation procedures for recycling
7 Limitation of LCI (interpreting LCI results)	9 Examples of conducting data quality assessment 10 Examples of performing sensitivity analysis
8 Study report	
ANNEX A Example of a data collection sheet B Examples of different allocation procedures	

3 Examples of developing functions, functional units and reference flows

3.1 Context of the standard

ISO 14041 states in 5.3.2 that:

— In defining the scope of an LCA study, a clear statement on the specification of the functions (performance characteristics) of the product shall be made.

— The functional unit defines the quantification of these identified functions. The functional unit shall be consistent with the goal and scope of the study.

— One of the primary purposes of a functional unit is to provide a reference to which the input and output data are normalized (in a mathematical sense). Therefore the functional unit shall be clearly defined and measurable.

— Having defined the functional unit, the amount of product which is necessary to fulfil the function shall be quantified. The result of this quantification is the reference flow.

and in 6.4.4 that:

— Based on the flow chart and systems boundaries, unit processes are interconnected to allow calculations on the complete system. This is accomplished by normalizing the flows of all unit processes in the system to the functional unit. The calculation should result in all system input and output data being referenced to the functional unit.

3.2 Overview

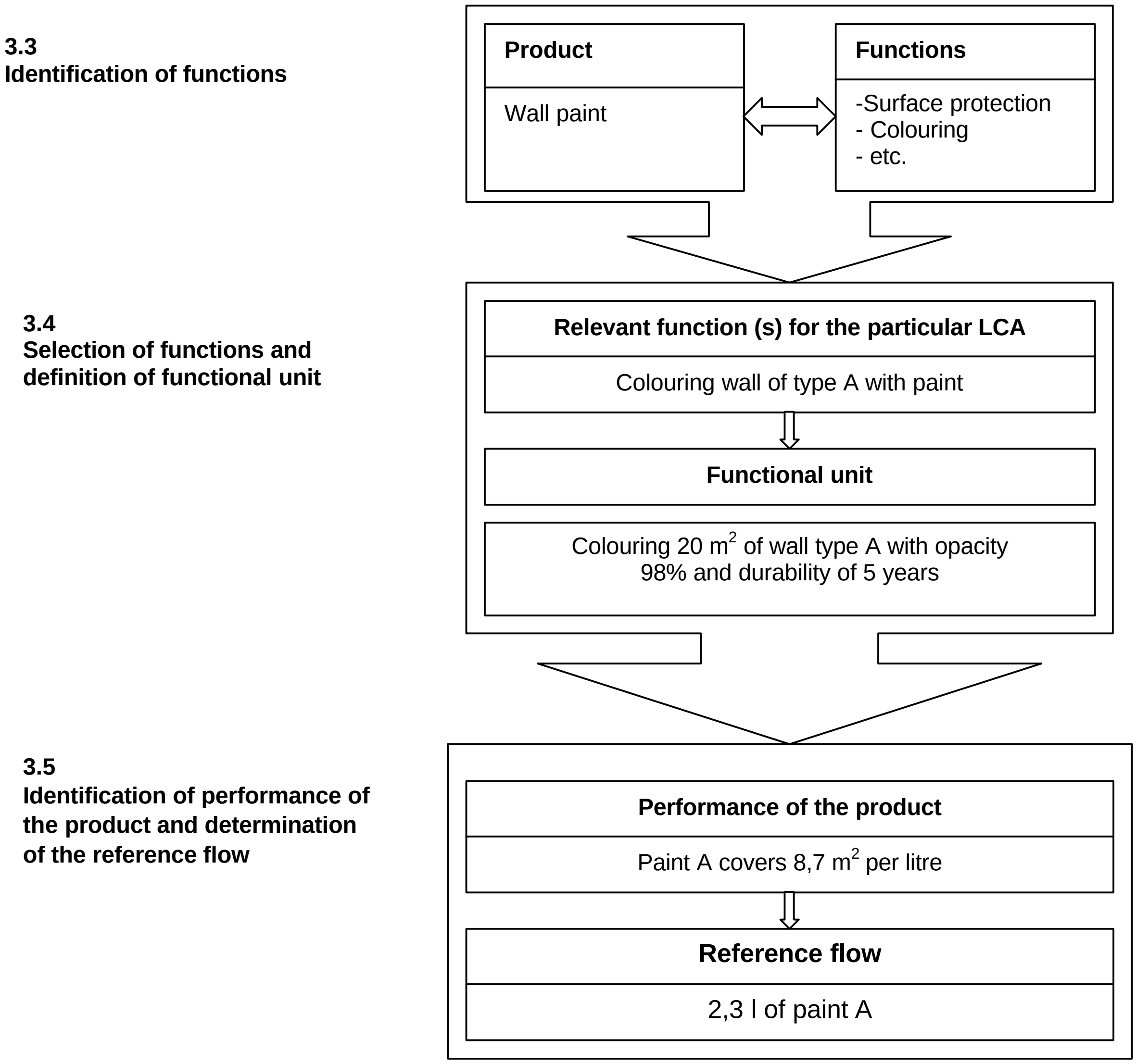
In defining a functional unit and determining the reference flows, the following steps can be distinguished:

— identification of functions;

— selection of functions and definition of functional unit;

— identification of performance of the product and determination of the reference flow.

The sequence of these steps is depicted in Figure 1 using the example of paint. This example is also used in the following text (3.3 to 3.5). Further examples are given in 3.6.



Note: It is possible to start with either the product or with the function itself.

Figure 1 – Overview of the example

3.3 Identification of functions

The purpose of the functional unit is to quantify the service delivered by the product system. The first step is thus to identify the purpose served by the product system, i.e. its function or functions.

The starting point for this procedure may be a specific product to be studied (e.g. wall paint) or it may be the final need or goal, which in some cases may be fulfilled by several distinct products (e.g. wall decoration, which may be fulfilled by both paint and wallpaper or a combination of these).

The functions are typically related to specific product or process properties, each of which may:

— fulfil specific needs and thereby have a use value, which typically creates economic value to the supplier of the product,

— affect the functioning of other economic systems (e.g. wallpaper may have a - small - insulation effect, thus affecting the heat requirement of the building).

3.4 Selection of functions and definition of functional unit

Not all functions may be relevant for a particular LCA. Thus, out of all the possible functions, the relevant ones must be identified.

For a solid interior wall, for example, surface protection may be unnecessary, while colouring is a relevant function of paint.

Subsequently, the relevant functions are quantified in the functional unit, which may be expressed as a combination of different parameters.

For wall colouring, the functional unit will typically have to specify the area to be covered (e.g. 20 m^2), the type of wall (especially regarding its absorption and binding properties), the ability of the paint to hide the underlying surface (e.g. 98 % opacity), and its useful life (e.g. 5 years).

In the case of multifunctional units, the different quantities are sometimes linked, e.g. a wall covering insulation material may be available with a pre-coloured surface, which makes colouring unnecessary, thus delivering both insulation and colouring. The functional unit could then be:

"20 m^2 wall covering with a heat resistance of 2 m·K/W, with a coloured surface of 98 % opacity, not requiring any other colouring for 5 years".

Other examples of multifunctional units are given in Table 2.

Table 2 – Examples of functional units for systems with multiple functions.

Example No.	**(1)**	**(2)**
System	**Paper recycling**	**Cogeneration**
Functions	- Recovery of waste paper, and - Production of de-inked pulp - etc.	- Generation of electric power, and - Production of steam - etc.
Selected function for a particular LCA	- Recovery of waste paper, or - Production of de-inked pulp	- Generation of electric power, or - Production of steam
Functional unit	- Recovery of 1 000 kg waste paper, or - Production of 1 000 kg pulp for newsprint	- Generation of 100 MW electricity, or - Production of 300 000 kg steam per hour at 125 °C and 0,3 MPa (3 bar)

3.5 Identification of performance of the product and determination of the reference flow

Having defined a certain functional unit, the next task is to determine the quantity of product which is necessary to fulfil the function quantified by the functional unit. This reference flow is related to the product's performance, and is typically determined as the result of a standardized measurement method. Of course, the nature of this measurement and calculation depends on the studied product.

For paint, the reference flow is typically expressed as the amount of litres necessary for covering the surface area as defined by the functional unit. For example, in a standardized test, paint A may be determined to cover 8,7 m^2 per litre (i.e. the performance of the product). Using the example illustrated in Figure 1, this requires 2,3 l to cover the 20 m^2 of the functional unit, provided that the conditions in the standardized test are similar to those required by the functional unit (with regard to surface type and opacity).

The functional unit may already be expressed in terms of quantities of products, so that the functional unit and the reference flow are identical. Table 2 gives examples of such functional units, which are already expressed in terms of quantities of products.

3.6 Additional examples

The following three examples further illustrate the procedure in developing functions, functional units, and reference flows.

Table 3 – Further examples of developing functions, functional units, and reference flows

Example No.	(1)	(2)	(3)
Product	Light bulb	Bottle	Hand drying
Functions	- Providing illumination - Generating heat - etc.	- Protection of beverage - Facilitating handling - Part of product image - etc.	- Drying hands - Removing bacteria - etc.
Selected function for a particular LCA	Providing illumination (outdoor lamp only)	Protection of beverage	Drying hands (hygienic function judged irrelevant)
Functional unit	300 lx in 50 000 h matching the daylight spectrum at 5 600 K.	50 000 l of beverage protected between tapping and consumption	1 000 pairs of hands dried
Performance of the product	100 lx with a lifetime of 10 000 h	0,5 l one-way bottle	One paper towel for drying one hand
Reference flow	15 daylight bulbs of 100 lx with a lifetime of 10 000 hours	100 000 one-way bottles of volume 0,5 l	2 000 paper towels

4 Examples of distinguishing functions of comparative systems

4.1 Context of the standard

ISO 14041 states in 5.3.2 that:

— Comparisons between systems shall be made on the basis of the same function, quantified by the same functional unit in the form of their reference flows.

— If additional functions of any of the systems are not taken into account in the comparison of functional units, then these omissions shall be documented. For example, systems A and B perform functions *x* and *y* which are represented by the selected functional unit, but system A also performs function *z*, which is not represented in the functional unit. It shall then be documented that function *z* is excluded from its functional unit. As an alternative, systems associated with the delivery of function *z* may be added to the boundary of system B to make the systems more comparable. In these cases, the processes selected shall be documented and justified.

4.2 Overview

When comparing product systems, special attention has to be made to confirm that the comparison is based on the same functional unit and equivalent methodological considerations, such as performance, system boundaries, data quality, allocation procedures, decision rules on evaluating inputs and outputs. In this chapter, some possible approaches will be described and illustrated by examples.

The general steps to be taken in comparative studies are illustrated in Figure 2.

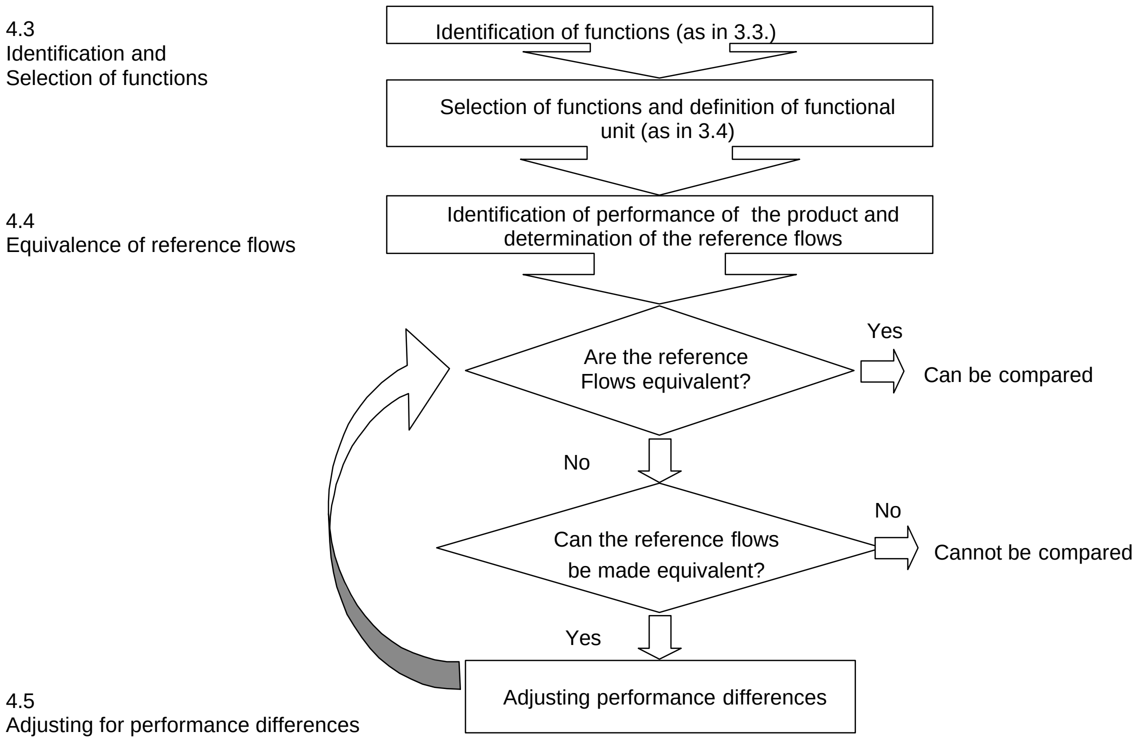


Figure 2 – Overview of the steps in comparative studies

4.3 Identification and selection of functions

The definition of the functional unit is closely bound to the goal of the study. If the goal is to compare product systems, special care will have to be paid in order to ensure that the comparison is valid, that any additional functions are identified and described, and that all relevant functions are taken into account.

Example 1: A study on waste management should include other functions than simply disposing of waste (i.e. the functions performed by the recycling systems in providing recycled material or energy).

Example 2: A study on electric household equipment should include the waste heat delivered to the building in which the equipment operates, as this influence the amount of heating and/or cooling required.

For comparative studies, the selection of functions becomes much more important than in non-comparative studies. Referring to the functions in Table 3:

— For bottles (example 2), leaving out of the image function of the packaging may lead to comparison of packagings that are technically similar (i.e. containing the same volume of beverage), but which the producer or customer will not accept as comparable.

— For hand-drying systems (example 3), leaving out the hygienic function may be regarded as unacceptable, e.g. in the food industry, where the bacteria-removing ability of paper towels may be regarded as such an advantage that a comparison to electrical hand-drying systems may not even be considered.

4.4 Equivalence of reference flows

The functional unit of the paint example from Clause 3 was "colouring 20 m^2 of wall type A with opacity 98 % and durability of 5 years". This functional unit can be supplied by several different reference functions:

2,3 l of paint A,

1,9 l of paint B,

1,7 l of paint C, etc.

These reference flows will have been calculated based on a test using standard conditions, concerning e.g. surface type and opacity.

The standardised test conditions and measurement methods must be appropriate to the intended comparison: In the hand drying example (example 3 in Table 3), it may be irrelevant to use a standardized test based on the technical properties of the paper such as mass, absorption-power and tensile strength, if the actual weight of paper used depends on the dispenser design. A more appropriate measure would then be data collected by weighing the paper stock at the start and the end of an adequate period in which the number of hands dried are determined by electronic surveillance of actual wash basins located in relevant institutions. Similarly, technical specifications of an electrical hand drier, such as the volume of air and its temperature, may be irrelevant as a basis for calculating the reference function, if the actual running time of the device is fixed by other factors, e.g. a built-in timer. Then, all that is needed is the running time and the electrical capacity of the equipment.

In the case of the light bulb (example 1 in Table 3), the functional unit of "300 lx in 50 000 h" may be provided by:

— 5 times 3 bulbs of 100 lx with a lifetime of 10 000 h each, or

— 10 times 2 bulbs of 150 lx with a lifetime of 5 000 h each.

The underlying premises of comparing 3 bulbs of 100 lx with 2 bulbs of 150 lx are:

— that the light spectrum of the two bulb types are comparable (or that the difference is acceptable to the user),

— that the 3 and 2 bulbs, respectively, can be placed so that the distribution of light is equal (or that the difference is acceptable to the user),

— that the sockets and other fixtures are not affected by the choice (in which case they would have to be included in the comparison).

Also, the two light bulbs were regarded as comparable in spite of their difference in lifetime. This difference is simply taken into account in the calculation of the reference flow. However, for long-lived products, such as refrigerators with lifetimes of 10 or 20 years, technology development may be a factor that cannot be disregarded. One refrigerator with a lifetime of 20 years cannot simply be compared to two successive, present-day refrigerators with a lifetime of 10 years. The refrigerators available 10 years from now are certain to be more energy efficient (i.e. lower energy input per functional unit) than the present, the energy efficiency of the second refrigerator of the 10 + 10 option must be determined by a trend projection, while the energy efficiency of the 20 years option is fixed.

The 100 000 one-way bottles of volume 0,5 l (example 2 in Table 3) may technically fulfil the same function of protecting 50 000 l of beverage, as would 12 500 returnable bottles of volume 0,4 l with a reuse rate of 90 %. However, in some situations the consumer may not always be able to distinguish between bottles of different volumes or masses. If the consumer regards 1 bottle equal to 1 bottle, the total consumption of beverage will decrease when the returnable bottles are introduced. In this case, the packaging cannot be studied independent of its contents. This is an example of the "No"-arrow leaving to the right in Figure 2. Of course, the goal of the study may then be redefined allowing for a comparison of beverage plus packaging taking into account the changes in consumption.

Another example of non-comparable functions (the "No"-arrow to the right in Figure 2), is that of two freezers, one with and one without quick-freeze option. If the quick-freeze option is regarded as an essential function by the consumer, the two freezers are simply not comparable and they cannot be made comparable by any calculation or system expansion. The same is true for the examples given at the end of 4.3.

In some systems with multiple functions, such as those in Table 2, the functions may be separated and delivered by several systems:

— Disposing the waste paper in an incineration plant and producing the pulp from virgin fibres may provide the same functional unit as the paper recycling system.

— Separate power and district heating units, respectively producing only electric power and only heat, may deliver the same functional unit as the co-generation plant.

However, some functions may be so intimately linked that separation is not possible. For example, the heat generation of a light bulb cannot be detached from its primary function.

In other situations, separations of two linked functions may be technically possible, but due to other aspects, the two separate functions may still not be regarded as comparable to the joint functions. An example of this is the combined freezer-refrigerator, which may or may not be compared to a freezer and separate refrigerator, depending on the acceptability of this choice to the consumer (the latter option will typically take up more space than a combined option with the same internal volumes).

Note that in most of the examples above, the equivalence of two products is determined by user acceptance. This acceptance, and thus whether two products are regarded as comparable or not, may be influenced by the price of the alternatives and by the additional information given along with the products, e.g. information on their environmental performance. Thus, for the purposes of product development or strategic management, it may be reasonable to compare two products which are not immediately regarded as equivalent, but where it is assumed that they will be regarded as equivalent under specific conditions of price and information.

4.5 Adjusting for performance differences

In those cases where the reference flows are immediately equivalent (as in the paint example at the top of 4.4) no adjustment is necessary.

In other cases, adjustment is necessary. The adjustment procedure follows the same principles as for co-product allocation, i.e. the preferred option is modification of the system boundaries to avoid the performance difference. In some cases, when this modification is not possible or feasible, allocation may be applied. In this section, examples are given of both options.

In the case of the light bulb in 4.4, it may be necessary to adjust the one of the systems to be compared (expanding it with an extra bulb socket). Another, more radical, example of such a system expansion or reconsideration of the studied functions, is that mentioned under the bottle example in 4.4, where the inclusion of the beverage was necessary.

A comparison of refrigerators may be based on their internal and/or external volume. The primary function is obviously related to their internal volume, but the external volume may a determining function, if the refrigerator is to be fitted into an existing kitchen. If the external volume is required to be equal, the internal volume may differ because of differences in insulation thickness. This can only be adjusted for by assuming differences in behaviour of the user (e.g. shopping more often, storing certain items outside the refrigerator, adding another secondary refrigerator elsewhere in the house). Each of these changes in behaviour will involve changes in different processes, which then have to be included in the study. If, on the other hand, the internal volume is required to be equal, a change in insulation thickness may require adjustments in the physical surroundings of the refrigerator (the other kitchen furniture). If both the internal and the external volumes are required to be equal, obviously no adjustment is possible which can accommodate the change in isolation thickness. This shows that the choice of required functions also determines the possible alternatives, which can be included in the study.

Adjustment by system expansion, as in the examples above, is not always possible. If one is studying only the freezing *or* refrigeration function of a combined freezer-refrigerator (e.g. for inclusion in a life cycle of a food product, which is refrigerated, but not frozen), there is no adjustment in the surroundings, which can adjust for the effect of the combination of the two functions. Thus, the inputs and outputs from the combined freezer-refrigerator must somehow be allocated between the two functions. This may be done based on a measure of the relative energy requirement for the two compartments, also known as the temperature-adjusted volume, calculated as:

$$V_{adj} = V_c \times (t_r - t_c) / (t_r - 5) ,$$

where V_c is the volume of the compartment, t_r, the room temperature, t_c the temperature of the compartment, and 5 °C is the reference temperature.

Note that, if analysing freezer-refrigerators *as products per se*, the comparability of two freezer-refrigerators with different ratios between volumes of the two compartments will eventually depend on the degree of substitutability in the eyes of the consumer. In this case, it is *not* adequate to adjust for the difference by technical coefficients (e.g. temperature-adjusted volumes).

5 Examples of establishing inputs and outputs of unit processes and system boundaries

5.1 Context of the standard

ISO 14041 states in 5.3.5 that:

— The initial identification is typically made using available data. Inputs and outputs should be more fully identified after additional data are collected during the course of the study, and subjected to a sensitivity analysis.

— The criteria and the assumptions on which they are established shall be clearly described.

— Several criteria are used in LCA practice to decide which inputs to be studied, including a) mass, b) energy and c) environmental relevance.

a) mass: an appropriate decision, when using mass as a criterion, would require the inclusion in the study of all inputs that cumulatively contribute more than a defined percentage to the mass input of the product system being modelled;

b) energy: similarly, an appropriate decision, when using energy as a criterion, would require the inclusion in the study those inputs that cumulatively contribute more than a defined percentage of the product system’s energy inputs;

c) environmental relevance: decisions on environmental relevance criteria should be made to include inputs that contribute more than an additional defined percentage to the estimated quantity of each individual data category of the product system.

— All of the selected inputs identified by this process should be modelled as elementary flows.

5.2 Overview

The goal of an LCA study provides direction for the selection of the individual data categories. The selection of individual data categories may include a comprehensive listing of inputs and outputs or may be specific to the particular questions that the study is examining.

Data categories from the system are listed in the goal and scope definition. Energy flows are typically included in an LCA study since information on these flows are often readily available and energy flows may have a significant effect on natural resource use and on emissions.

Decisions regarding the material flows that are selected for inclusion in the scope of an LCA study will impact on the results. It is important to include all significant material flows that could affect the interpretation of the study.

The process to select material inputs, outputs and the system boundaries is outlined in Figure 3.

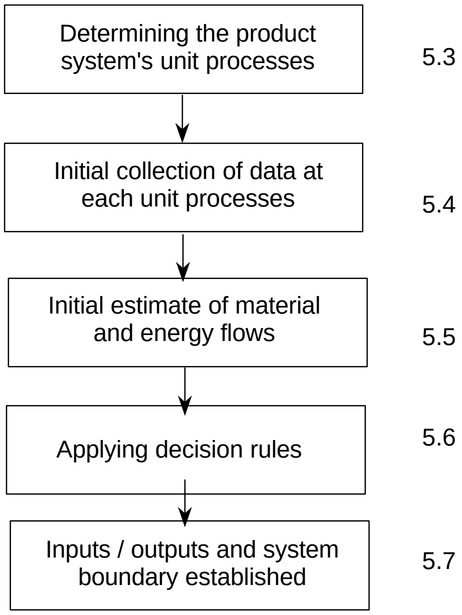


Figure 3 – Overview of establishing inputs, outputs and system boundaries

5.3 Determining the product system’s unit processes and their boundaries

The unit processes that comprise a product system should be compiled for the product-supply and use chains, consistent with the goal and scope of the study. Figure 4 shows a conceptual description of a unit process with its associated inputs and outputs. An example of a unit process might be "aluminium smelting”, a part of a product system for an aluminium product. This unit process transforms raw or intermediate material (refined alumina) inputs associated with ancillary material, energy and environmental releases into a “*intermediate product* ” that is further processed within the product system. With this information, specific processes that perform the transformations may be established. Subsequently, a listing of specific reporting locations that are relevant to the goal of the study is prepared.

In order to establish the unit process boundaries, the sites within the population of interest may be contacted to determine the smallest portions of the product system for which data are available. Since there is variability in the specific processes that are performed by a particular site, unit process boundaries are established with a view to minimizing the need for allocation procedures.

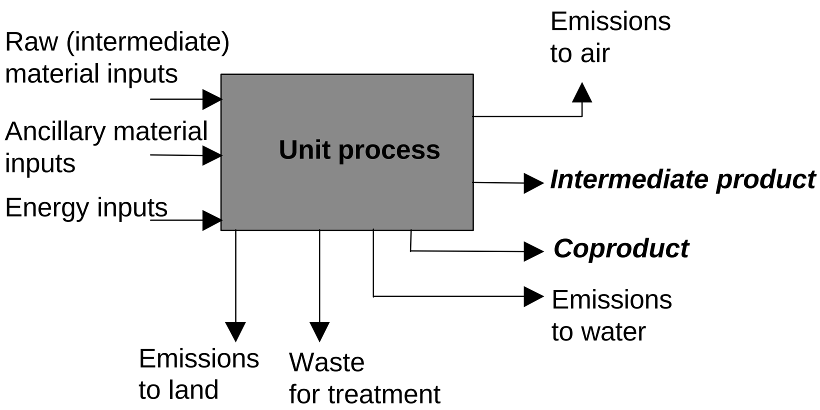
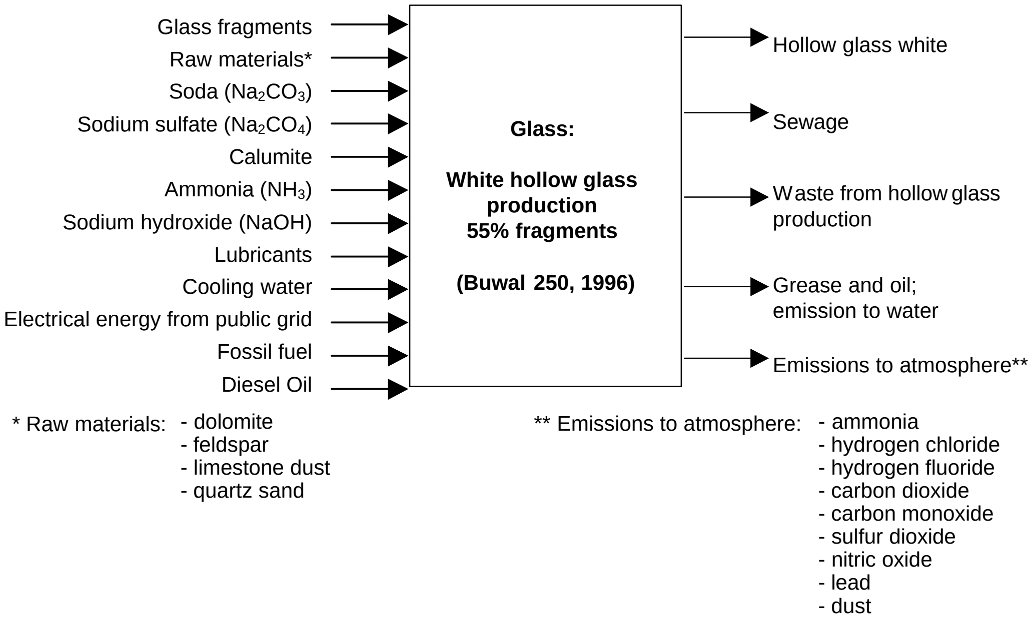


Figure 4 – Conceptual example of unit process description

Another example of unit process description for white hollow glass production is shown in Figure 5 with associated list of inputs and outputs.



Module: Glass: white hollow glass production, 55 % fragments (Buwal 250, 1996) **Section:** packaging production			
Input	**Material categories**	**Unit**	**Quantity**
Glass fragments; secondary raw material	Product from other systems	kg	601,30
Dolomite; raw material	Elementary flow	kg	72,50
Feldspar; raw material	Elementary flow	kg	31,10
Limestone dust; raw material	Elementary flow	kg	27,00
Quartz sand; raw material	Elementary flow	kg	253,10
Soda (Na_2CO_3)	Intermediate product	kg	62,80
Sodium sulfate (Na_2SO_4)	Intermediate product	kg	3,20
Calumite	Intermediate product	kg	6,50
Ammonia (NH_3)	Intermediate product	kg	0,30
Sodium hydroxide (NaOH 50%)	Intermediate product	kg	21,40
Lubricants	Intermediate product	kg	0,662
Cooling water	Elementary flow	m³	1,70
Electrical energy from public grid (Swiss)	Intermediate product	kW·h	291,00
Diesel oil (production)	Intermediate product	kg	0,14
Fuel (integrated incineration)	Intermediate product	kg	152,4
Output			
Hollow glass white	Intermediate product	kg	1 000,00
Sewage	Intermediate product	m³	1,68
Waste from hollow glass production	Intermediate product	kg	4,44
Special waste from hollow glass production	Intermediate product	kg	0,65
Ammonia; emission to atmosphere	Elementary flow	g	0,72
Hydrogen chloride; emission to atmosphere	Elementary flow	g	53,3
Hydrogen fluoride; emission to atmosphere	Elementary flow	g	14,80
Carbon dioxide; emission to atmosphere	Elementary flow	kg	521
Carbon monoxide; emission to atmosphere	Elementary flow	g	27,80
Sulfur dioxide; emission to atmosphere	Elementary flow	g	1 292,00
Nitric oxide; emission to atmosphere	Elementary flow	g	1 158,80
Lead; emission to atmosphere	Elementary flow	g	44,60
Dust; emission to atmosphere	Elementary flow	g	589,60
Grease and oil; emission to water	Elementary flow	g	42,00

Figure 5 – Example of unit process description for white hollow glass production

5.4 Initial collection of data at each unit processes

The data collection procedure may be guided by the results of an initial data availability survey involving a small sample of the sites from which data eventually are going to be collected.

It may be a good idea to design and send to the suppliers a questionnaire, which they can copy and send on to their suppliers. But a questionnaire alone is not enough. Even the most explicit questionnaire with examples and explanations does not guarantee that everybody understands the questions in the same way. Therefore, the answers must be treated with care. Contact by telephone, before and after sending the questionnaire, may increase both the number of answers and the quality of the answers. For important data it may be necessary to visit the company in order to ensure that the data is correct.

When working with foreign companies, special attention should be paid to units and abbreviations which may appear obvious in one's native tongue but may be incomprehensible or misleading to others, e.g. "bbl", "el", "ha", "t", "ton". Ask that no abbreviations are used, and that SI units are used when relevant.

The general information requested for each unit processes may be structured as follows:

— reference unit (e.g. "Data has been given per kilogram oil"). The reference unit of a unit process could be one or more incoming or outgoing material or energy flows. The reference unit may also be a certain amount of time (e.g. "annual production");

— what the data includes, i.e. the beginning and the end of the unit process and whether or not the data includes ancillary substances, packaging, cleaning, administration, marketing, research & development, laboratory facilities, activities related to employees (heating, lighting, work clothes, transportation, canteen, toilet facilities), machines and maintenance. It should also be stated whether the data are for normal operating conditions only or includes also shut-down/start-up conditions and reasonably foreseeable or emergency situations;

— geographical location of the facility;

— the applied technology/the technological level;

— if the unit process produces more than one product, data relevant for the allocation of the environmental exchanges, if allocation has been made and if so, how this was done.

The following information may need to be specified for every single input or output:

— the period during which data has been collected, and whether the data represents an average of the whole indicated period, or only parts of it;

— how data has been collected and how representative they are (e.g. "1 sample per month", "continuous measurements", "calculated from recorded consumption", "estimated"), including number of measuring sites, measuring methods, calculation methods (including how the average is calculated), and the significance of possible exclusions and assumptions;

— name and affiliation of the person responsible for the data collection and the date of collection;

— validation procedure.

The inputs and outputs should, as far as possible, be given with indication of uncertainty (preferably with statistical information such as standard deviation and type of distribution, but at least as an interval). It should be stated where an ingoing flow is coming from (e.g. "water from private waterworks") as well as the destination of outgoing flows (e.g. "to waste water treatment facility"). It should be easy to see if the flow comes from/goes to nature (e.g. purified waste water to a stream) or to/from another technical process (e.g. sludge to agricultural land). For certain flows it is also important to state the quality (e.g. dry matter content, oil content, energy content).

Transports are preferably reported as separate unit processes. A transport system can be divided in the fixed infrastructure (e.g. roads, lines, pipes, ports, stations), the movable carrier (e.g. truck, plane, container) and the energy source (e.g. diesel, electricity). For each mode of conveyance the following values may be reported:

— The energy type and amount in relation to both distance (e.g. in km) and transport performance (mass × distance, e.g. kg·km),

— The environmental exchanges in relation to both distance and transport performance,

— The average load percentages including empty return trips, and the adjustment factors used for this.

5.5 Initial estimate of material and energy flows

Based on the initial data collection, an initial estimate of the material and energy flows is prepared as shown by the example of glass bottles in Tables 4 and 5.

Table 4 – Solids inputs for glass bottles listed decreasing order of content

Material	Amount	Unit	Running total
Coal (lignite and pit coal)[a]	53,1	kg	53,1
Crude oil [a]	43,7	kg	96,8
Sand [a]	8,7	kg	105,5
Scrap of tinplate and steel from other systems [a]	7,3	kg	112,8
Limestone and lime [a]	6,9	kg	119,7
Broken glass pieces from other systems [a]	6,8	kg	126,5
Natural gas (6.22 m^3) [a]	4,9	kg	131,4
Sodium hydroxide [a]	4,5	kg	135,9
Wood [a]	4,0	kg	139,9
Sodium chloride [a]	2,7	kg	142,6
Sulfuric acid [a]	1,1	kg	143,7
Glue [a]	0,7	kg	144,4
Kaolin and binder [b]	0,6	kg	
Soap [b]	0,5	kg	
Sodium sulphate	0,06	kg	
Hypochlorite	0,05	kg	
Roller oil	0,048	kg	
Chlorine	0,030	kg	
Sodium chlorate	0,030	kg	
Oxygen	0,030	kg	
Tin [b]	0,025	kg	
Anthracite coal	0,020	kg	
Sulfur dioxide	0,020	kg	
Not specified	0,012	kg	
Peroxide	0,005	kg	
Hydrogen	0,002	kg	
Cobalt oxide	0,002	kg	
Total	145,8	kg	
+ Printing ink and colours[b] no data available			
+ Water	7 000	litres	

[a] See text under decision rules for mass contribution in 5.6.1

[b] See text under decision rules for environmental relevance in 5.6.3

Table 5 – Energy consuming processes in the life cycle stages of glass bottles divided among directly consumed electricity, thermal processes etc., transport and feedstock

Energy consuming process - directly used	Electricity %	Thermal etc. %	Transport %	Feedstock %
Extraction and refining of raw materials	0,1	2,6		
Glass production	4,5	14,2		
Rinsing and filling	64,4	61,4		
Use (refrigeration at consumers)	15,9			
Recovery (cleaning of glass pieces)	0,1			
Waste handling inclusive incineration				2,9
Labels - total life cycle	4,4	8,8		60,6
Bottle tops - total life cycle	10,2	10,5		12,9
Crates - total life cycle	0,5	2,5		23,6
Distribution			79,1	
Transport except distribution			20,9	
Total %	100	100	100	100
Total in kW·h or MJ	78 kW·h	750 MJ	743 MJ	67 MJ

5.6 Applying decision rules

The following decision rules may be applied consecutively.

5.6.1 Decision rules for mass contribution

Decisions for excluding material inputs based on mass have been used frequently. Rules of thumb such as excluding materials that contribute less than five percent to the mass inputs of a unit process or those that contribute less than one percent to the overall mass input of the system have been popularised in the literature. However, from a data quality viewpoint, preference should be given to decision rules that are based on the cumulative contribution to the system under study rather than the contribution of any individual materials. An appropriate decision rule would be to require the inclusion of all materials that have a cumulative total of more than a fixed percentage of the total mass inputs to the product system.

Example: For the glass bottle system in Table 4, a decision rule has been established that the sum of all materials included shall be more than 99 % of the total mass inflow to the system. Based on this decision rule only the materials marked with a single asterisk are included. The remaining materials may be removed from further analysis.

5.6.2 Decision rules for energy

Basing the inclusion of processes on mass criteria alone can result in important data being discounted. While mass is an important indicator of the significance of materials, some materials are much more energy intensive than others. It is therefore advisable to supplement the decision rule based on mass with a decision rule based on the cumulative energy requirement of the analysed system.

Example: For the glass bottle system, the energy requirements are listed in Table 5. This analysis shows some important processes, which might have been excluded if the analysis had been based only on dry mass of inputs. Both "Rinsing and filling" and "Use (refrigeration at consumers)" have very low inputs of materials, but account for a major share of the energy requirement. A decision rule for inclusion may be that the sum of all processes included shall be more than 99% of the total energy requirement of the system.

5.6.3 Decision rules for environmental relevance

The mass criterion applied in the glass example may be supplemented by a criterion for environmental relevance. A qualitative assessment of materials that are expected to contribute with important toxic emissions leads to the additional inclusion of the materials marked with footnote b in Table 4.

A quantitative decision rule for environmental relevance may be established for each individual data category or impact assessment category. In the glass bottle example, a decision rule is applied that includes processes whose cumulative contribution covers 90 % of the initially calculated quantity of each category.

Example: For the impact category "Human toxicity, air" this involves a closer examination of the data categories "Lead to air" and "Nitrogen oxides to air", as these constitute 90 % of the contribution to the category (see Table 6). This lead to the inclusion of glass production as a separate process due to the lead emission (introduced from the broken glass pieces received from other systems).

Table 6 – Processes of the glass bottle system responsible for at least 90 % of the contribution to the potential impact category "Human toxicity, air"

Lead (56 %)	Glass production (72 %) Other thermal processes (20 %) Electricity production (7 %) Transport processes (1%)
Nitrogen oxides (34%)	Transport processes (73%) Thermal processes etc. (15%) Electricity production (12%)

5.7 Inputs, outputs and system boundaries established

Using the process outlined above, the material inputs and outputs to be included in the LCI study and system boundary are established. This process allows for the seeking of additional information in proportion to the absolute magnitude of the mass, energy and environmental relevance. These decision rules therefore, direct wise and selective expenditure of time and resources for those areas most able to improve the overall quality of the LCI study.

6 Examples of avoiding allocation

6.1 Context of the standard

For allocation procedures, ISO 14041 states in 6.5.2 that:

— The allocation procedure used for each unit process of which the inputs and outputs are allocated shall be documented and justified.

and in 6.5.3 that:

— the following stepwise procedure shall be applied:

a) **Step 1:** Wherever possible, allocation should be avoided by:

1) dividing the unit process to be allocated into two or more sub-processes.

2) expanding the product system to include the additional functions related to the coproducts, taking into account the requirements of 5.3.2.

6.2 Overview

This chapter presents two examples for avoiding allocation that exemplifies the flexibility in applying the specific guidance of ISO 14041. The two examples in 6.3 and 6.4 are depicted in Figure 6.

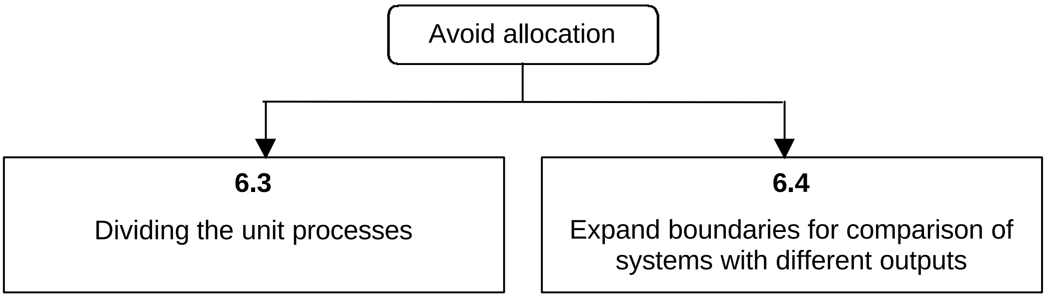


Figure 6 – Overview of examples for avoiding allocation

The example in 6.3 describes the allocation avoidance by dividing the unit process. The example in 6.4 consists in expanding the system boundaries so that two modified options produce the same amounts of the same final products. This method guarantees that both the options produce the same amounts of say, plastic and heat, so that the overall resource consumption and environmental emissions can be compared.

6.3 Example of allocation avoidance by dividing the unit process to be allocated into two or more processes

Allocation is sometimes applied to products whose manufacture is not intrinsically linked. This may occur, for instance, when data collection is performed at a given location without going deeper in detail regarding specific processes occurring at that site.

Unnecessary allocation may bring about significant biases, as illustrated in Figure 7. In this case, allocation between chromium-coated coils and organic-coated coils brings about the allocation of environmental inputs and outputs associated with solvent consumption occurring on the organic coating line to the chromium-coated coil production. This may have consequences on all the upstream stages (if the yields are different for both coating lines).

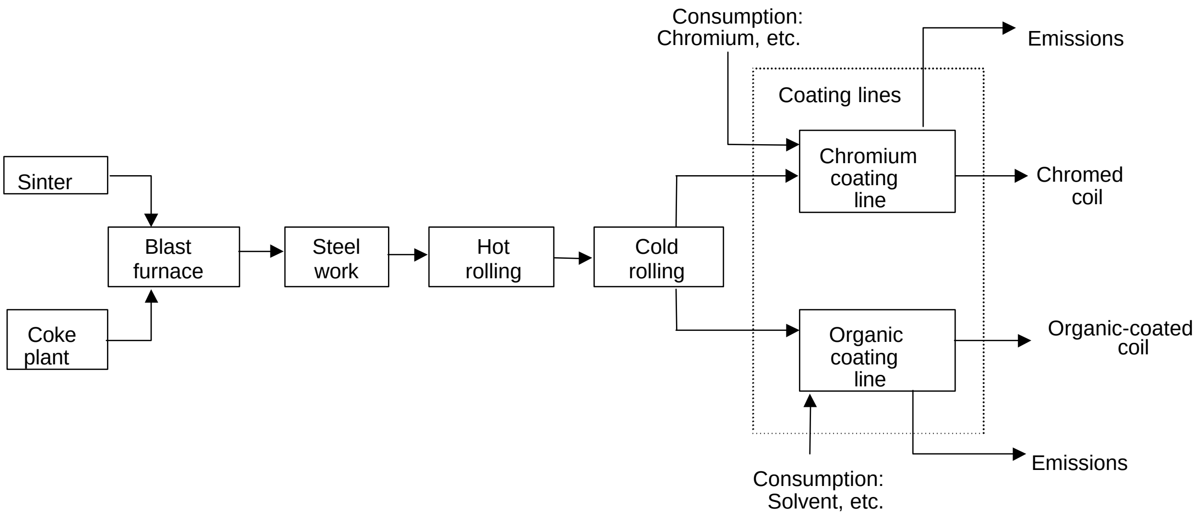


Figure 7 – System where allocation may be avoided through a more precise data collection and dividing into two different subsystems

In this case, if data collection encompasses both chromium and organic coating, it will be necessary to allocate environmental inputs and outputs between the two lines. Accordingly, it is necessary to collect data separately in order to break the single coating line unit process into two processes.

6.4 Example of allocation avoidance by expanding the boundaries for comparison of systems with different outputs

Plastic packaging materials, after consumer use, can be processed into different products, depending on the recovery option. As an example, Figure 8 shows inputs and outputs associated with alternate processes of 1 kg of plastic waste. One example includes material recycling and has as its coproduct, plastic film. The other option includes energy recovery and produces heat as a coproduct. Since material recycling and energy recovery yield different products, the consumption of resources and the environmental emissions due to these two options cannot be compared directly.

To facilitate a comparison of the inventories of these two options, an expansion of the system boundaries can be applied, as illustrated in Figure 9.

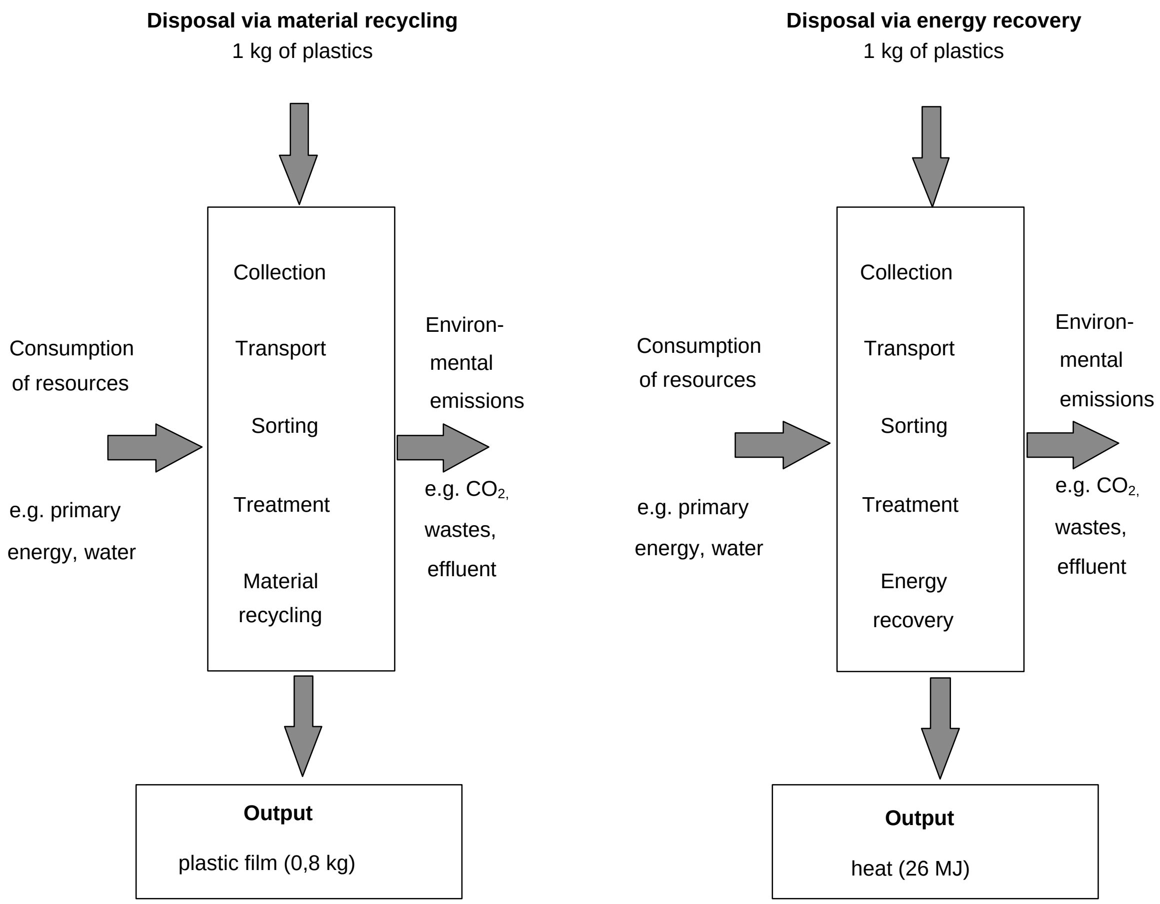


Figure 8 – Example of material recycling and energy recovery

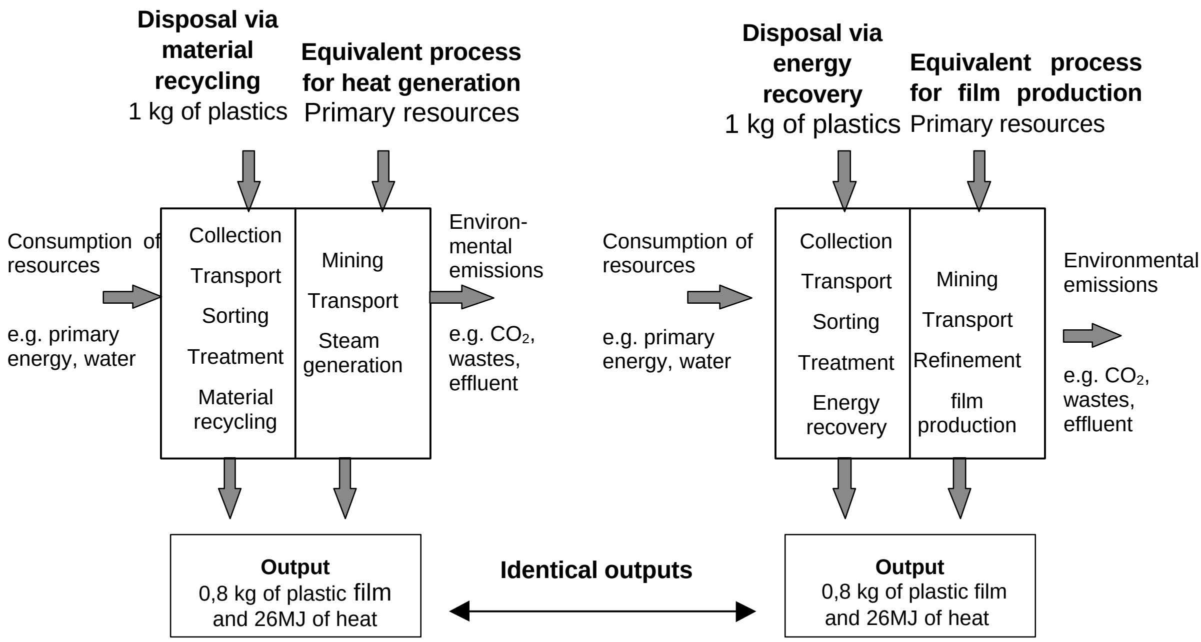


Figure 9 – Example of an expansion of the system boundaries

This method expands the system boundaries so that the two modified options produce the same amounts of the same final products. The material recycling pathway is supplemented with an equivalent process (also known as a complementary process) generating 26 MJ of heat from primary resources. Likewise, an equivalent process generating 0,8 kg of plastic film from primary resources is added to the energy recovery pathway. Since this method guarantees that both the options produce the same amounts of plastic and heat, the overall resource consumption and environmental emissions can be compared.

The same approach can be used for comparisons of more than two recycling options with different products.

The supplementary processes to be added to the systems must be those that would actually be involved when switching between the analysed systems. To identify this, it is necessary to know:

— whether the production volume of the studied product systems fluctuate in time (in which case different sub-markets with their technologies may be relevant), or the production volume is constant (in which case the base-load marginal is applicable),

— for each sub-market independently, whether a specific unit process is affected directly (in which case this unit process is applicable), or the inputs are delivered through an open market, in which case it is also necessary to know:

  — whether any of the processes or technologies supplying the market are constrained (in which case they are not applicable, since their output will not change in spite of changes in demand),

  — which of the unconstrained suppliers/technologies has the highest or lowest production costs and consequently is the marginal supplier/technology when the demand for the supplementary product is generally decreasing or increasing, respectively.

See also 9.3.3 regarding technology coverage.

7 Examples of allocation

7.1 Context of the Standard

For allocation procedures, ISO 14041 states in 6.5.3 that:

— the following stepwise procedure shall be applied:

a) **Step 2:** where allocation cannot be avoided, the inputs and outputs of the system should be partitioned between its different products or functions in a way which reflects the underlying physical relationships between them; i.e. they shall reflect the way in which the inputs and outputs are changed by quantitative changes in the products or functions delivered by the system.

b) **Step 3:** where physical relationship alone cannot be established or used as the basis for allocation, the inputs should be allocated between the products and functions in a way which reflects other relationships between them. For example, input and output data might be allocated between coproducts in proportion to the economic value of the products.

7.2 Overview

The two selected examples are presented according to the prescribed stepwise procedure in 6.4.2 of ISO 14041 and based on the answer to the question: Is it possible to allocate in a way which reflects underlining physical relationships? One example answer yes, i.e. example of 7.3.1, in which allocation is conducted in a purely physical relationships. 7.3.2 provides an example where a physical relationships to allocate is not available and a purely economic way is adopted.

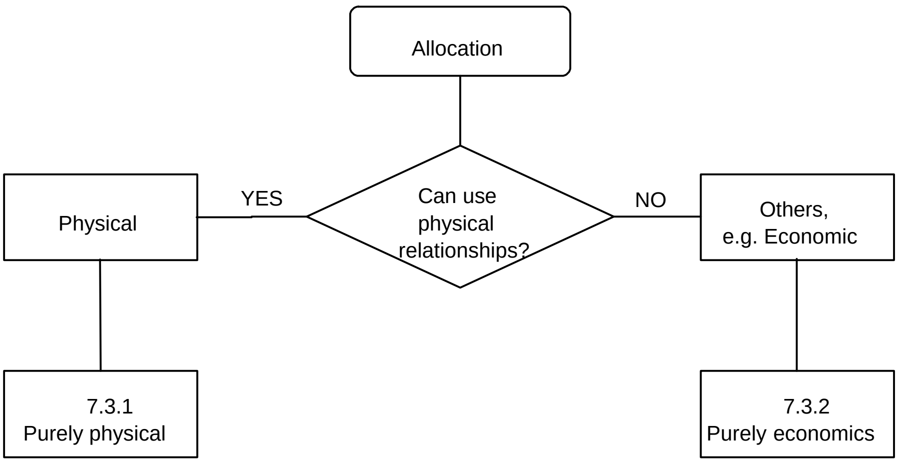


Figure 10 – Overview of examples for allocation procedure

7.3 Description of the examples

7.3.1 Example of allocation on a purely physical relationships

In LCI-studies with a packaging system under investigation, the distribution from the filling factory to the wholesalers / retailers includes the packaging filled with goods. If the goal of the study insists on carrying out a life cycle inventory on the packages separately from that on their contents, then the problem may be solved by the allocation of the inventory data between the packages and the contents.

The amounts of fuel consumption and emission releases by the transports depend upon various factors such as load, speed and road conditions, but this example focuses on mass and volume of the load only. For simplicity[1], a linear interdependence of the fuel consumption and the load mass is applied to the truck with load. On the other hand, the fuel amount consumed by the truck without load on the return way is assumed to be constant (Figure 11). Emissions are also assumed to be caused correspondingly by the transports.

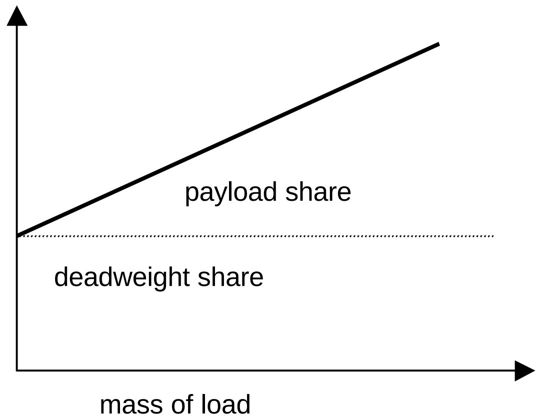


Figure 11 – Fuel consumption of a truck in dependence on the load transported

The purpose of a transport is moving the largest possible amount of commodities, but a part of the truck capacity is always consumed by packages needed for the transport. Hence, the mass of packages as well as their design have a considerable effect on the maximum load of commodities. For the allocation, first, it has to be checked whether the truck is used up to mass capacity or volume capacity, and the share of the package must be determined. This requires five basic values as follows:

— maximum mass capacity of the truck,

— maximum volume capacity of the truck,

— density of the contents,

— actual load of the contents,

— actual load of the packages.

The following are two examples of allocation for mass and volume capacity uses of the truck, on the assumption that the maximum capacity of the truck is equal to the actual load:

1) Mass capacity use: A truck with a maximum load mass of 40 tons and a maximum payload of 25 tons transports 25 tons of filled packages, i.e., its full mass capacity. The share of packages is 5 tons. This means that 20 % of the capacity is consumed by packages, and, correspondingly, 20 % of environmental impacts caused by this transport (deadweight and payload) have to be assigned to the packages.

2) Volume capacity use: The same truck is loaded up to volume capacity and carries 17 tons of packages filled with the same commodity. Two tons of 17 tons of the maximum payload are package. Due to the large volume of the packaging material used, the load of commodities carried is only 15 tons, which corresponds to 60 % of the maximum payload. Forty percent of the truck capacity are consumed by

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[1] Any simplification need to be justified to avoid its misuse.

packages and, in correspondence to this, 40 % of the deadweight transportation of the truck are partitioned to packages. With regard to the overall payload, however, the percentage of packages is only 12 %, which means that only 12 % of environmental impacts caused by the payload are assigned to the packages.

7.3.2 Example of allocation on a purely economic basis

Bitumen is produced from petroleum refineries as well as other co-products such as gasoline, kerosene, gas oil and fuel oil. The refinery process may yield 5 % mass fraction of bitumen and 95 % mass fraction of the other co-products. For simplicity[2], the petroleum extraction, transportation and refinery process are considered as one unit process with a set $\{D_i\}$ of input and output data, including depletion of petroleum resources, fuel consumption and emissions by transportation and emissions, e.g. VOC, and waste, e.g. spent catalysts, from the refinery process, as shown in Figure 12.

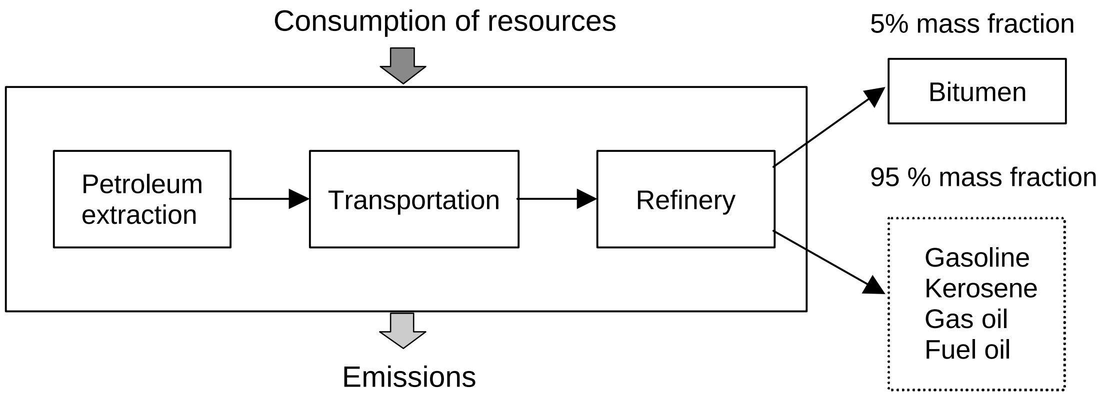


Figure 12 – Example of bitumen production process

There is no way to avoid allocation by identifying a process which only produces bitumen, because all the co-products are made from the same input as crude oil.

Therefore, an allocation factor *F* has to be found which shares the set $\{D_i\}$ of data into bitumen and the other co-products in an appropriate way. All data $\{D_i\}$ multiplied by this factor *F* will represent of the environment loads which have to be attributed to the bitumen.

The next step is to determine whether a physical parameter can be identified as a basis for calculating the allocation factor. According to ISO 14041, these physical relationships must reflect the way in which the inputs and outputs are changed by quantitative changes in the products delivered by the system.

One procedure which is used to find such a physical parameter is to vary the ratio between the different co-products in order to find out how the data set varies with this change in product output. In the example of the lacquering of different metal parts A and B (see ISO 14041, Clause B.3, EXAMPLE 3), a physical parameter (the specific surface of the products to be lacquered) could be identified and justified by such quantitative changes in the products delivered by the system, i.e. by varying the ratio of the two sorts of lacquered metal pieces.

This procedure fails because the ratio between the mass of bitumen and the mass of the other co-products can only be varied in a small range which involves a significant change of the process parameters including energy consumption.

2 Any simplification needs to be justified to avoid its misuse.

In such a case, any physical parameter, e.g., mass, feedstock energy, thermal conductivity, viscosity, specific mass, etc., could be taken into consideration in order to identify the physical parameter which reflects the underlying physical relationship between bitumen and the other co-products. Mass has sometimes been applied in the case, but none of all those parameters can be justified to be preferable to the other ones. The fact that in this example the ratio between the bitumen and the other co-products cannot be varied indicates that the physical allocation cannot be applied.

Therefore, the third choice proposed in ISO 14041, i.e., the economic allocation, can be applied. It may be assumed that, as an average of the last three years, the market price of 1 kg of bitumen is 50 % of the market price of the average of the other co-products. This means that the causation of drilling, pumping, transporting and refining oil is rather the production of the other co-products than the production of bitumen. Then the allocation factor is $F = 0,5 \times 0,05 = 0,025$, which means that 2,5 % of each of the data $\{D_i\}$ will be allocated to the bitumen and 97,5 % of these data to the other co-products. Note that in the case of mass allocation bitumen would have carried 5 % of each of the data $\{D_i\}$.

8 Example of applying allocation procedures for recycling

8.1 Context of the standard

For recycling, ISO 14041 states in 6.5.4 that:

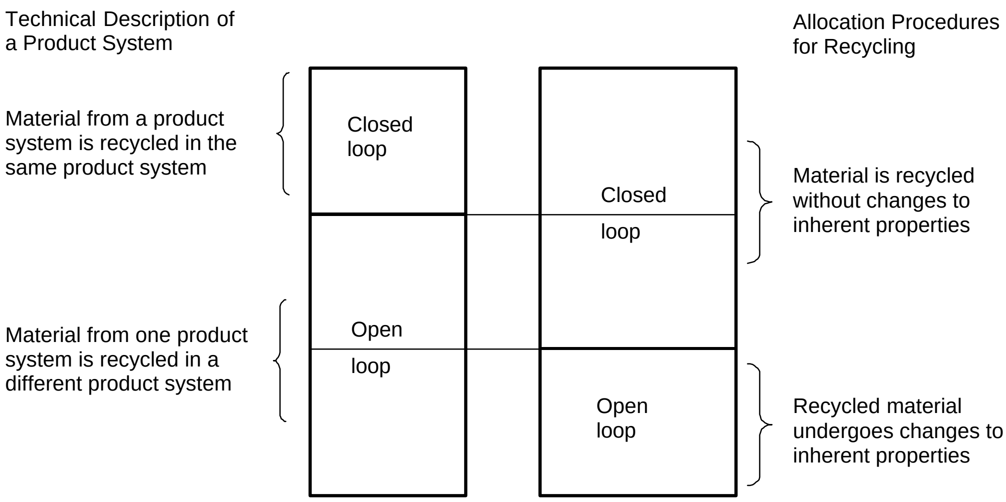
— The allocation principles and procedures in 6.5.2 and 6.5.3 also apply to reuse and recycling situations. However, these situations require additional elaboration for the following reasons:

a) reuse and recycling (as well as composting, energy recovery and other processes which can be assimilated to reuse / recycling) may imply that the inputs and outputs associated with unit processes for extraction and processing of raw materials and final disposal of products are to be shared by more than one product system;

b) reuse and recycling may change the inherent properties of materials in subsequent use;

c) specific care is needed for system boundaries definition regarding recovery processes.

— Several allocation procedures are applicable for reuse and recycling. Changes in the inherent properties of materials shall be taken into account. Some procedures are outlined conceptually in Figure 4 of ISO 14041 and are distinguished in the following to illustrate how the above constraints can be addressed:



ISO 14041 – Figure 4 – Distinction between a technical description of a product system and allocation procedures for recycling

- a closed-loop allocation procedure applies to closed-loop product systems. It also applies to open-loop product systems, where no changes occur in the inherent properties of the recycled material. In such cases, the need for allocation is avoided since the use of secondary material displaces the use of virgin (primary) materials. However, the first use of virgin materials in applicable open-loop product systems may follow an open-loop allocation procedure outlined below;

- an open-loop allocation procedure applies to open-loop product systems where the material is recycled into other product systems and the material undergoes a change to its inherent properties. The allocation procedures for the shared unit processes mentioned in 6.5.3 should use, as the basis for allocation:

  - physical properties;

  - economic value (e.g. scrap value in relation to primary value); or

  - the number of subsequent uses of the recycled material.

- In addition, particularly for the recovery processes between the original and subsequent product system, the system boundary shall be identified and justified, ensuring that the allocation principles are observed as described in 6.5.2.

8.2 Overview

Three examples are provided; a closed loop case, an open loop case with closed loop procedure and a “pure” open loop case. The observation is made that allocation does not occur in closed loop and open loop (with closed loop procedure) recycling.

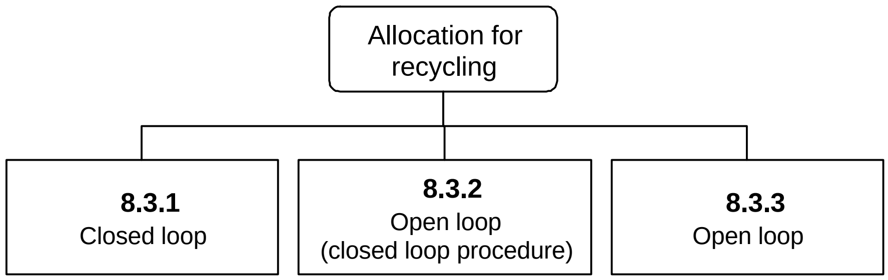


Figure 13 – Overview for examples for recycling

8.3 Description of the examples

8.3.1 Example of closed loop recycling

A manufacturing process for HFC-134a, used as an alternative fluorocarbon refrigerant, is supplied with ethylene as one raw material, but a portion (0,05 units) of the ethylene leaves without reaction and is handled as substance to be recycled.

A closed loop allocation procedure can be applied to this scenario. The ethylene of the output displaces an equivalent amount of the input ethylene needed for the next batch, and the net consumption of ethylene is decreased to 0,95 units per manufacturing cycle.

The ethylene leaving the process is possibly not as clean as the virgin ethylene entering the input stream. A cleaning step might be added to the process to bring the recycled ethylene to the same level of quality as in the virgin material, which results in an expansion of the boundaries of the system studied. The closed loop allocation procedure remains applicable to the expanded system and avoids the need for allocation. The flow diagram in this case is shown in Figure 14.

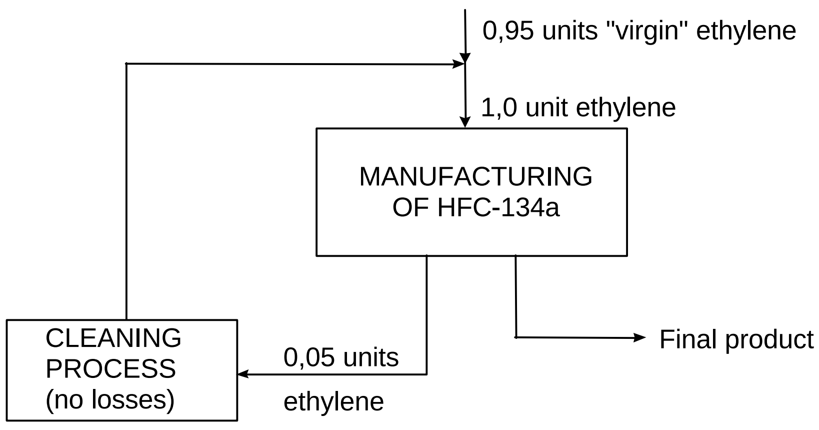


Figure 14 – Flow diagram of closed loop recycling example

The net consumption of ethylene remains the same in the example, but other consumption and releases, for example electricity consumption, are added to the studied life cycle inventory of this system.

8.3.2 Example of open-loop with closed loop recycling procedure

There are cases where recycling in a product-specific system participates in product independent material pools for recycled glass, steel, aluminium, etc. The product-specific system delivers secondary raw material into that pool and is supplied with secondary material by the pool. If the import and export of secondary raw material between the pool and product specific life cycle are equivalent, the product specific system can be modelled as closed loop recycling without any problem. If there is a net export or import of secondary raw material, an open-loop (with closed-loop procedure) is in existence and further considerations regarding the handling of co-products are necessary. An allocation problem comes up concerning the recycling benefit of these exports or imports.

This example of the aluminium production clarifies the problem and gives a proposal for the solution of the allocation problem. Figure 15 shows a simplified life cycle of an aluminium package. In the “real“ technology requiring the specification of aluminium for package, a fixed percentage of secondary aluminium content is used. Therefore, the amount of recovered scrap metal is higher than the input capacity in this system. That is why a net scrap output participates in an open loop recycling outside the product specific system. The net scrap output into the pool can be considered a co-product.

The proposal to solve this allocation problem is to expand the system boundaries. The key question is "What is the benefit of the net scrap output from the aluminium production?" The answer is that the additional amount of scrap in the aluminium market :

— increases the amount of available secondary aluminium which

— displaces virgin aluminium metals.

With the method "expansion of the system boundary to avoid allocation" it is possible to calculate the effects of the net aluminium scrap output from the product specific system regarding the displacement of virgin aluminium metal in other product systems, for example in the production of aluminium window frames (Figure 16). The treatment of the net scrap output from the recycling furnace in Figure 15 causes additional environmental impacts. But for displacing the virgin aluminium production of *w* kg in Figure 16, environmental benefits are to be considered. With this procedure the difference between producing aluminium from secondary raw material and producing the same product, i.e. aluminium from virgin material is calculated. The difference in the environmental effects between both is the benefit of the net scrap output and will be credited to the aluminium package system under investigation.

For a product specific consideration these effects can be calculated in a closed loop recycling model based on an adjusted technology split of virgin aluminium production and secondary aluminium production (Figure 17). This requires that the processes “virgin aluminium production“ and “recycling furnace“ are identical or not very different in the product specific system and the rest of the aluminium market and that the inherent properties of the primary and secondary aluminium are identical or similar.

This closed loop recycling model makes the following assumptions:

— production of the same amount of aluminium packaging material as in Figure 15, namely 100 kg,

— recovery of the same product-specific amount of aluminium scrap, namely 110 kg,

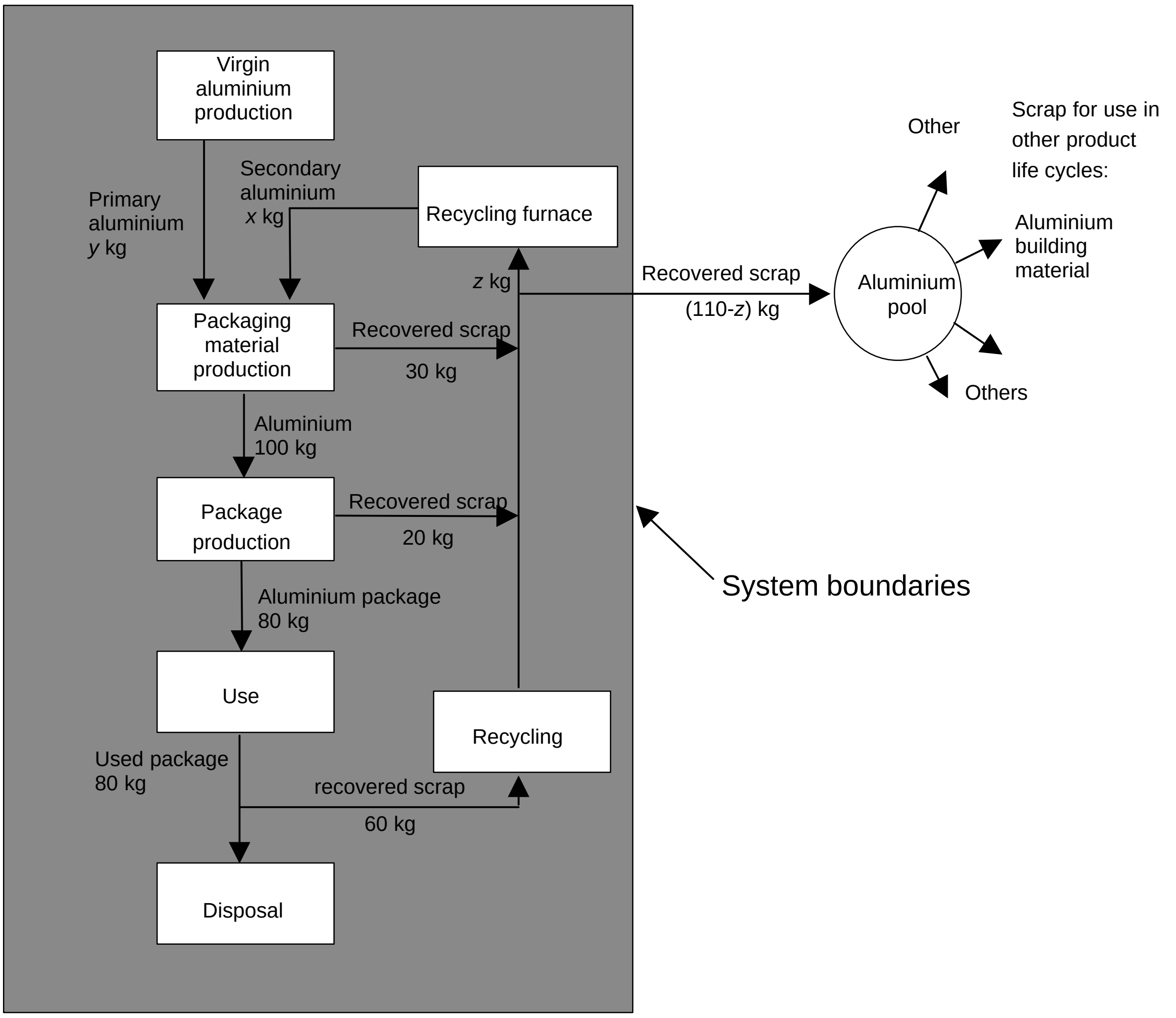


Figure 15 – Open-loop with closed-loop recycling procedure for aluminium package (fictitious numbers)

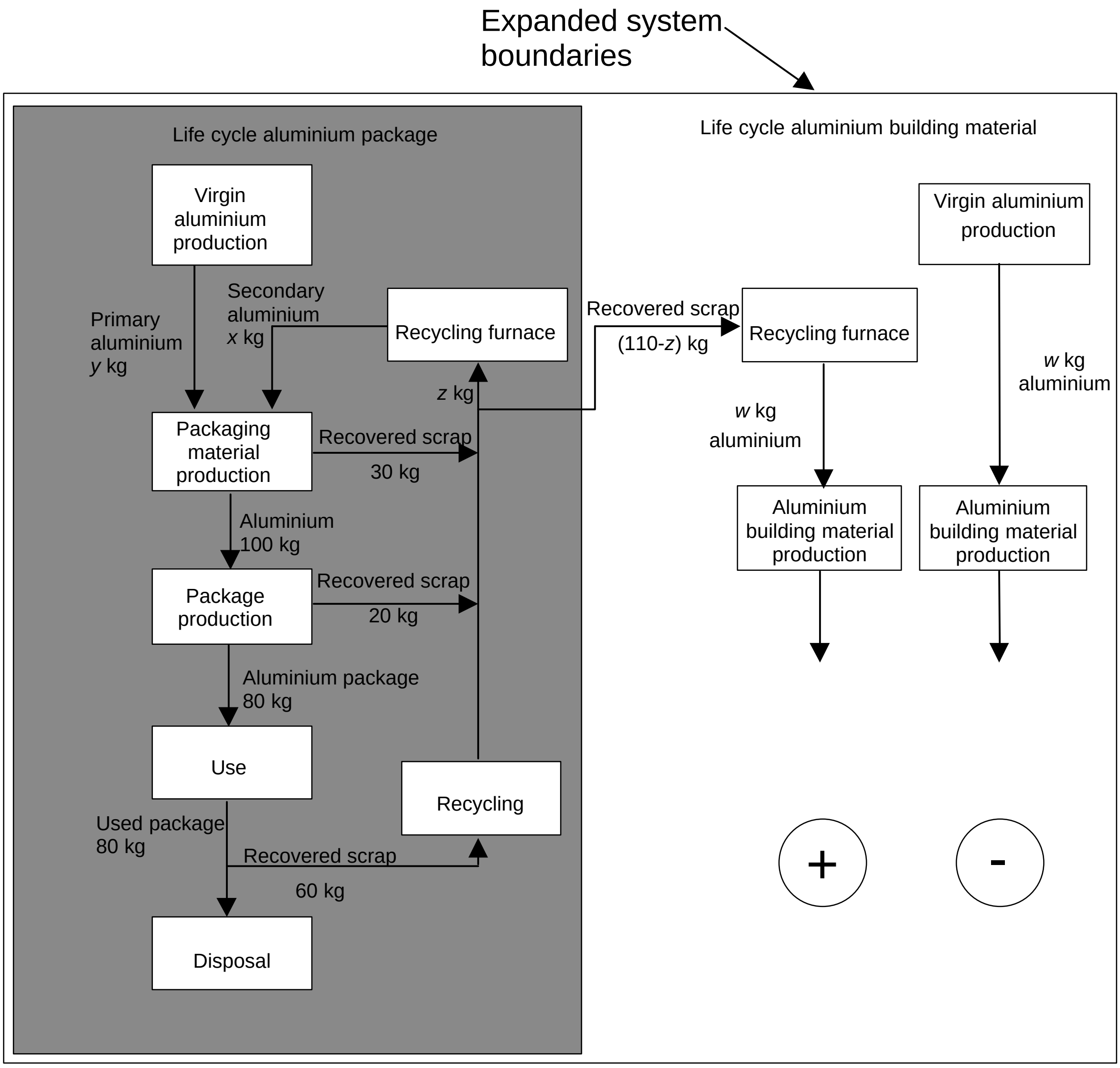


Figure 16 – Open-loop with closed-loop recycling procedure for aluminium package with expanded system boundaries (example for other product life cycles: aluminium building material)

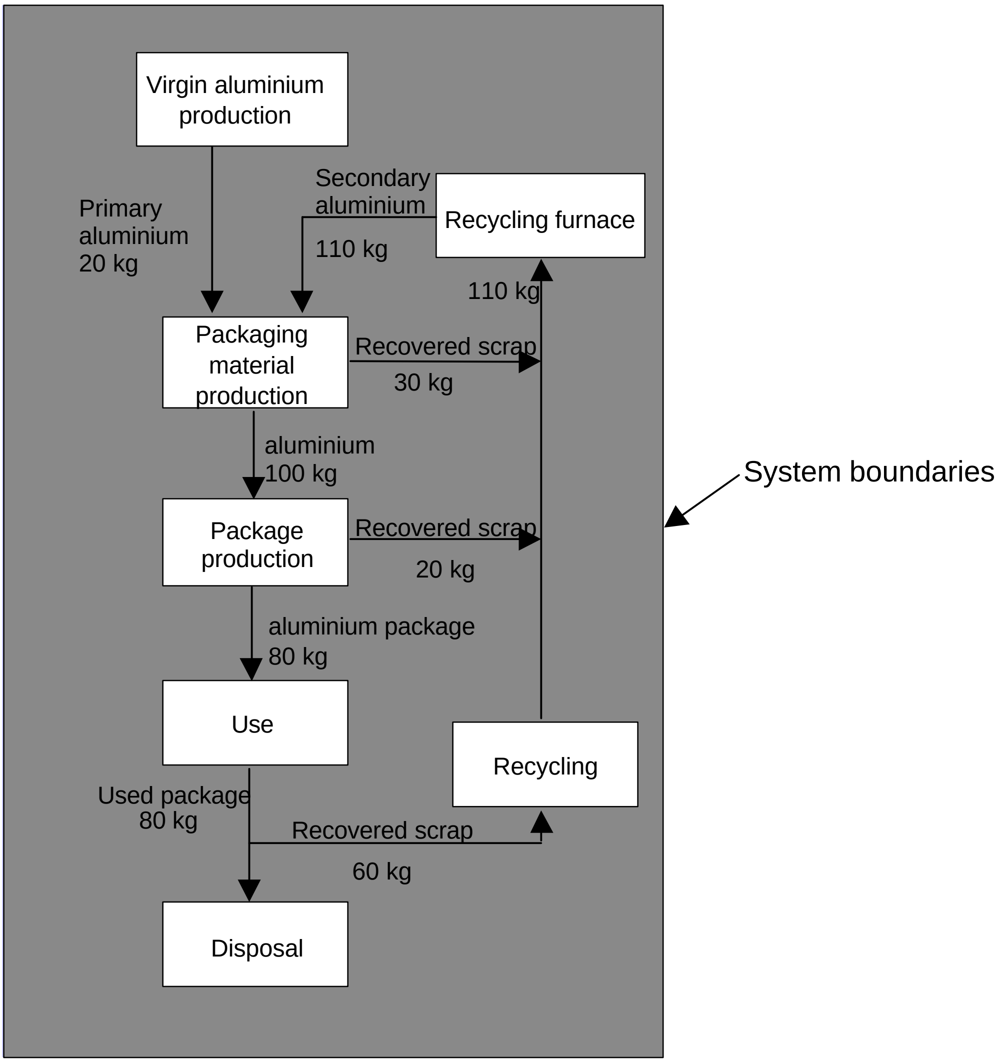


Figure 17 – Closed loop recycling model for aluminium package with an adjusted product-specific technology split

8.3.3 Open loop recycling

This example is about a hypothetical kraft bleached paperboard product system, KBPB. It does not reflect a specific product system or category on this broad term neither accurate figures are provided. The allocation procedures utilised are based on both physical properties and the number of subsequent uses of the recycled materials. The steps to describe the example are indicated in the flow diagram of Figure 18.

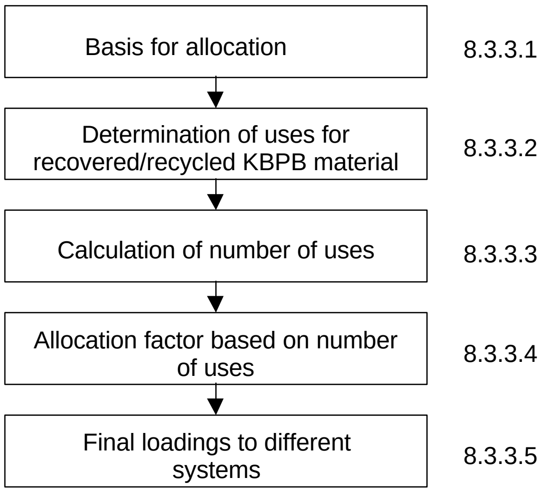


Figure 18 – Steps to describe the example of open loop recycling

8.3.3.1 Basis for allocation

The "basis" on which the allocation factor is made-- that is, the total loading which will be allocated between the primary product and the products derived from recycled fibres -- reflects the loadings associated with the primary (original) product system, until the end of the product life. The following diagram in Figure 19 illustrates the allocation basis.

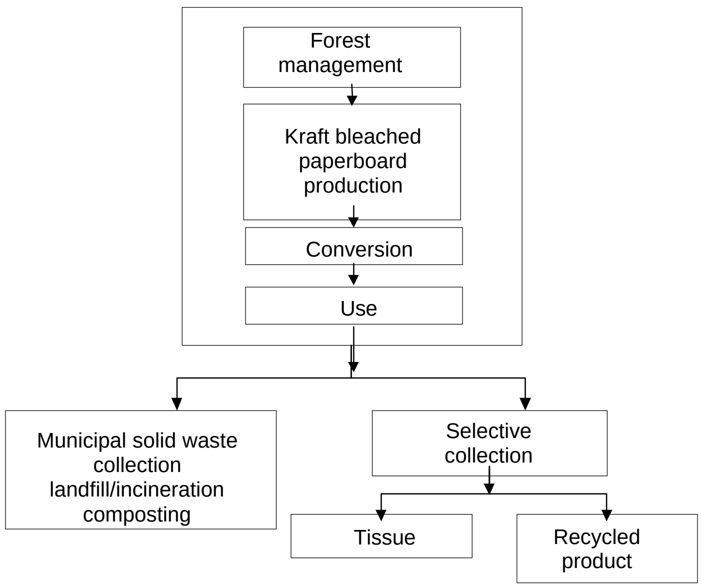


Figure 19 – Allocation basis

8.3.3.2 Determination of uses for recovered/recycled kraft bleached paperboard (KBPB) material

Two major different uses are known for the discarded kraft bleached paperboard-tissue paper and other recycled paper products. The difference stands in the fact that tissue paper once used, is discarded. In the other hand, other recycled paper products are susceptible of further recovering and recycling.

In this example, we consider that 30 % of the kraft bleached paperboard, KBPB, is directed to municipal solid waste, (MSW), disposal facilities and that 70% enters into recovering and recycling paper product systems, as indicated in the above.

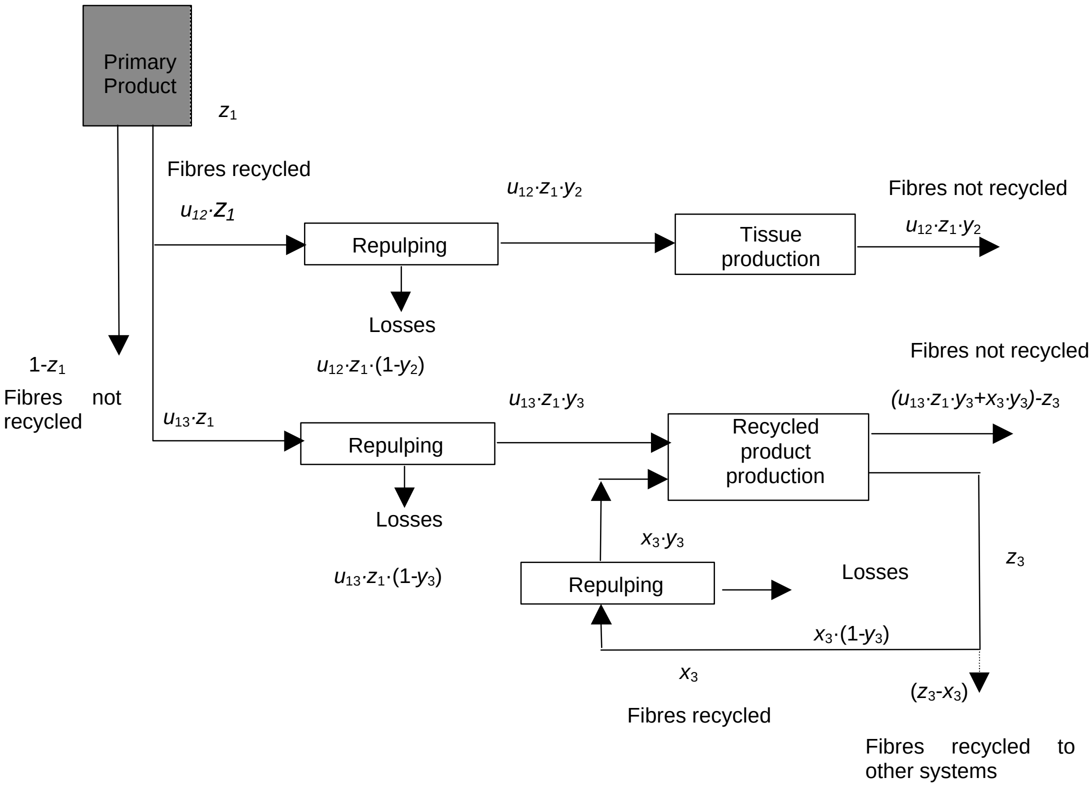


Figure 20 – Different uses of the discarded and recovered KBPB products
(z_1 = 0,70, u_{12} = 0,25, u_{13} = 0,75, $z_3 = x_3$ = 0,5, $y_2 = y_3$ = 1,0)

The recycling product systems receiving the 70 % of the recovered KBPB are of different nature. 25 % of the total recovered fibre is estimated to go into tissue paper production. 75 % of the total recovered KBPB fibre is estimated to go into other product systems which practice either closed or open recycling. Figure 20 provides information about the material flow and the fractions. All variables are explained in the following section. All yields are considered equal to 1,0 (no losses) in order to facilitate calculations.

8.3.3.3 Calculation of the number of uses

With the help of Figure 20, it is possible to estimate the total number of uses (u). Values for the different variables as well as the formulation are in the following.

The following variables are defined:

- z_1 is the fraction of primary product which is recovered after a first use and then recycled;
- u_{12} is the fraction of z_1 fibres which are recycled into tissue;
- u_{13} is the fraction of z_1 fibres which are recycled into recycled products;

$$u_{12} + u_{13} = 1{,}0$$

y_2 is the yield of repulped fibres for tissue production;

y_3 is the yield of repulped fibres for recycled products;

z_3 is the fraction of recycled product which is recycled again;

x_3 is the fraction of recycled product which is recycled in a closed loop;

$z_3 = x_3$ (assumes no open loop recycling of post consumer fibres).

For the recycling scenario presented in Figure 20, the total number of uses (u) for z_1 fibres can be calculated as follows:

u	=	1	(first use of the primary product recycled)
	+	$z_1 \cdot u_{12} \cdot y_2$	(tissue use)
	+	$z_1 \cdot u_{13} \cdot y_3$	(recycled product use; the first pass)
	+	$z_1 \cdot u_{13} \cdot y_3 \cdot (z_3 \cdot y_3)$	(recycled product use; the second pass)
	+	$z_1 \cdot u_{13} \cdot y_3 \cdot (z_3 \cdot y_3)^2$	(recycled product use; the third pass)
		……..	
	+	$z_1 \cdot u_{13} \cdot y_3 \cdot (z_3 \cdot y_3)^{n-1}$	(recycled product use; the *n*th pass)

or,

$$u = 1 + (z_1 \cdot u_{12} \cdot y_2) + (z_1 \cdot u_{13} \cdot y_3) \cdot \left[1 + (z_3 \cdot y_3) + (z_3 \cdot y_3)^2 + \ldots\right]$$

Calculating the last element and grouping will result in,

$$u = 1 + z_1 \cdot [(u_{12} \cdot y_2) + (u_{13} \cdot y_3)(1/(1-(z_3 \cdot y_3)))]$$

Therefore, the total number of uses for the fibre sent to recycling is,

$$u = 1 + z_1 \cdot [(u_{12} \cdot y_2) + (u_{13} \cdot y_3) \cdot (1/1-(z_3 \cdot y_3)))]$$

8.3.3.4 Calculation of the allocation factor based on the number of uses

Once the number of uses (u) has been estimated as 2,225 per the above, the allocation factor is calculated as follows.

If a fraction z_1 of the total production of kraft bleached paperboard, KBPB, becomes recovered for subsequent uses in other product systems, then $(1 - z_1)$ of the total loading remains in the primary (original) system, and z_1 of the total loadings goes to the totality of the recycled product uses. It must be remembered that the primary (original) material also shares on this fraction. The final loading allocation factor for the primary (original) product system will be then:

$$(1 - z_1) + (z_1 / u)$$

This allocation approach, based on the total number of uses plus original, applies to both the primary (original) product system and to the totality of the recycled product systems. Since $z_1 = 0{,}70$ and $u = 2{,}225$, the allocation factor for the primary (original) product system is

$$(1-0{,}70)+(0{,}70\,/\,2{,}225)=0{,}30+0{,}3146=0{,}6146$$

Likewise, the totality of the recycled product uses will receive, from the recycled KBPB recovered material, an allocation factor equal to

$$z_1 \cdot (u-1)\,/\,u =$$

$$0{,}70\times(2{,}225-1)\,/\,2{,}225=0{,}3854$$

The sum of the fractions of the original and the totality of the recycled product systems has to be $1{,}0$. It is important to check it.

$$0{,}6146 + 0{,}3854 = 1{,}000$$

8.3.3.5 Final loadings to the different systems

The loadings are allocated to the different systems as follows.

For the primary (original) system, all the KBPB system loadings per functional unit are multiplied by the allocation factor of 0,6146. That represents the importance of the open loop recycling in the results of the inventory analysis. An appreciable fraction of the primary (original) product system is passed on to the totality of the recycled product systems. This is an expression of the fact that the material sent to recycling is similar to a valuable co-product rather than a valueless waste.

For the different recycled products, the “raw material” fibre coming from the KBPB system brings with it the remaining fraction of the loadings or (1 – 0,6146) = 0,3854. In the case of the tissue system whereby no further recovery will take place and once used it is discarded, the allocation factor will remain 0,3854 for that recycled “raw material” fibre in use.

For the other recycled paper product system, the allocation factor of 0,3854 that will come with the “raw material” fibre, for the totality of uses, could be further reduced according to the knowledge of the system and the percentage or fraction of these products known to be recovered and recycled again in other systems. In this example, $z_3 = x_3$ thus no further open loop recycling takes place.

In both cases, to the loadings coming with the “raw material” fibre there will be need to add the specific loadings due to the reprocessing, etc. of the raw material fibre into the new product system.

If further open loop recycling had occurred, the allocation procedure will be similar to the one already described in the above. Again, it is important that the assumptions and calculations on the allocation factor will be checked, as done in the above, to indicate that the fractions add up to 1,0.

9 Examples of conducting data quality assessment

9.1 Context of the standard

ISO 14041 states in 5.3.6 that:

- Data quality requirements should be included for the following parameters:
  - time-related coverage;
  - geographical coverage;

  - technology coverage;

- In all studies, the following additional data quality requirements shall be considered:

  - precision;

  - completeness;

  - representativeness;

  - consistency;

  - reproducibility;

in 6.3 that:

- When data are collected from published literature, the source shall be referenced. For those data collected from literature which are significant for the conclusions of the study, the published literature which supplies details about the relevant data collection process, the time when data have been collected and about further data quality indicators, shall be referenced. If such data do not meet the initial data quality requirements, this shall be stated.

in 6.4.2 that:

- For each data category and for each reporting location where missing data are identified, the treatment of the missing data and data gaps should result in:

  - a “non-zero” data value which is justified;

  - a "zero" data value if justified; or

  - a calculated value based on the reported values from unit processes employing similar technology.

and in Clause 7 that:

- The interpretation shall include a data quality assessment and sensitivity analyses on significant inputs, outputs and methodological choices in order to understand the uncertainty of the results.

9.2 Overview

In general, a comprehensive life cycle inventory involves the collection and integration of hundreds upon thousands of pieces of data regarding the product, process, or activity under study. Depending on the scope of the study, information is gathered from different companies and even continents. As such, it is essential that the management of data quality is an integral part of the overall process.

Figure 21 shows the sequential procedure to conduct data quality assessment, and the following describe several data quality requirements and data quality indicators that may be used in a life cycle inventory.

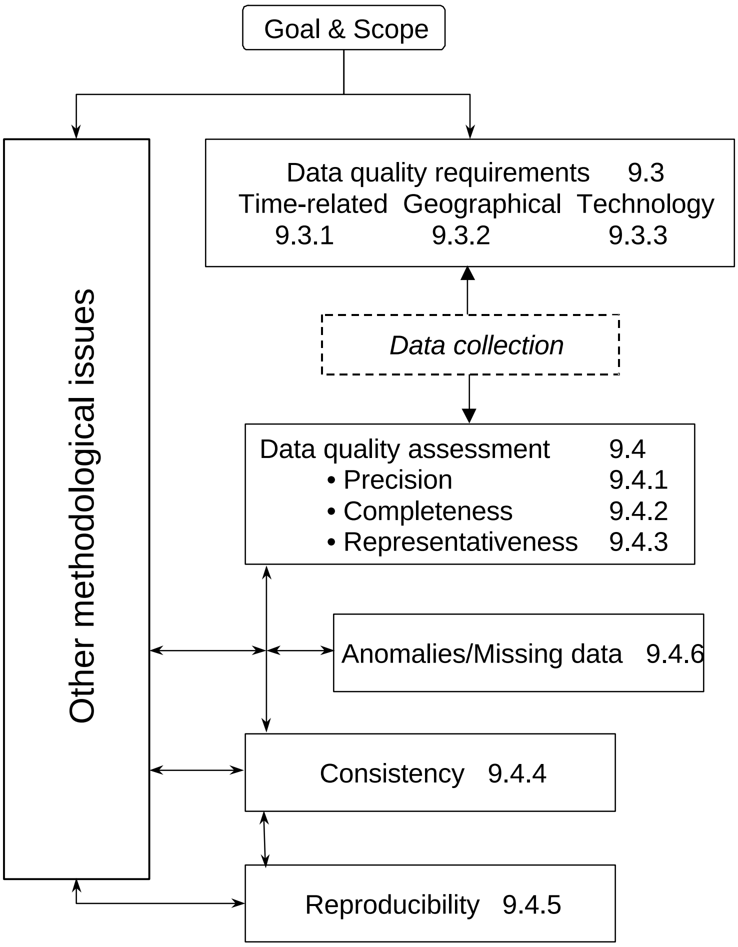


Figure 21 – Overview of conducting data quality assessment

9.3 Data requirements to establish the specific listing of sites

The goal of the study establishes the basis for defining the time-related, geographical and technology requirements of a study. This scoping activity is an important first step to establish data quality requirements.

9.3.1 Time-related coverage

Several decisions need to be taken regarding the vintage and source of the data to be used in the study. The age of the primary data which are site specific, and the secondary (e.g., published sources) may be used for a distinction.

Example: The targets may be established using both types of sources

The targets may be established using both types of data collected from different sources. They could be for instance,

— primary data collected from a specific company within the last year;

— secondary data using published sources within the last five years.

When the age of data deviates from these targets, it should be noted.

Actual measured data could be considered the best since it provides an understanding of variability inherent in the processes to be modelled. However, properly documented, calculated, or estimated data provide valuable input. Where possible, data are collected for a minimum period representing a year. Such data provide clarity on potential seasonal effects, natural process variation and accidental events. In addition to the specific period of study, it is useful to review the previous 12 month period to check the consistency and to help identify any anomalies or potential reporting errors.

9.3.2 Geographical coverage

The spatial boundary may include the site-specific facilities that are part of the product system for a study, which may be further specified to a specific region or market sector. A study could equally extend to a site-specific location. In a site-specific situation, each participating company initially determines the amount of product that is included, which is subsequently traced back through the supply chain and forward to recovery, recycling and disposal. The supply chain may extend beyond the specific region where the product is sold, especially when raw material suppliers are participating in the study.

The documentation of this product flow is important since it sets the framework for the management of information and subsequent data quality assessment. This list also provides a possible basis for the assessment of completeness of the study.

9.3.3 Technology coverage

The listing of the specific sites that report data is used to define the inherent characteristics of the production, process and environmental control technologies. Summaries from trade associations and government agencies provide a useful inspection for subsequent review of representativeness of the industry sectors.

This goal of the study will dictate the mixture of technologies and the number of locations by technology type that will be included. Technological development should be taken into account when the total life cycle covers a time period where such a development can be expected. See the example of the refrigerator in 4.4.

9.4 Requirements to characterize the quality of the data

ISO14041 shows the five indicators to characterize the quality of the data and the collection and integration methods.

9.4.1 Precision

This is a measure of the variability of data values for each data category expressed. It measures the spread or variability of the data set values about the mean of the data set. For each data category, the mean and the standard deviation of reported values are calculated and reported for each unit process in the product system. These precision measures may be used to assess the uncertainty of reported values and aid the sensitivity analysis of the study results.

9.4.2 Completeness

Completeness of primary process data can be indicated by the percentage of locations for which primary data are available out of the total number in existence. A percentage target is generally agreed for each type of unit process before data collection begins. In comparative studies, the goal is that each product system has an equivalent level of completeness. Targets should typically be set at a certain level (e.g.70 %).

9.4.3 Representativeness

This is an indicator of the qualitative assessment of degree to which the data set reflects the true population of interest. In essence, this assessment is similar to completeness but is focused on the geographic, temporal and technological dimensions of the product system. This indicator measures the degree to which the data values used in the study present a true and accurate measurement of the population of interest. The indicator may also provide information about the fraction of total production capacity represented by the participants. Any major variances identified are examined and explained.

Example: Biased sampling with completeness.

In order to introduce the unit emission of carbon dioxide per kilowatt hour in a certain region or electricity production-network, surveying each conversion plant to summarise for averaged value may be a proper approach. Nevertheless, if the survey is done on a network that is 96 % hydropower and the remaining 4 % being conventional coal plant, neglecting the emission from 4 % thermal would introduce an important bias.

9.4.4 Consistency

Consistency is a qualitative understanding of how uniform the study methodology is applied to the various components of the study. This quality measure is one of the most important to manage in the inventory process. There are a number of steps that must be taken to ensure consistency. One of these is communication. In a study which involves a number of different companies which in turn collected data from different sites in different countries and continents, there must be a clear understanding of what data is being requested, how it is measured, how it is reported, and how it is used.

Example: Reported value from a number of manufacturers

When establishing average emission and energy data for the material inputs to a production process, it is required to collect numerical data from a number of manufacturers. Some of them may be reported using the published data such as national standard, while others introduce their own status by actual measuring. Since they are not uniform in collecting methods or precision, and if it is difficult to avoid the mixing of distinct approach, a preliminary assessment should be held to check the deviation.

For instance, investigating the emissions to air, the comparison may show that the emission of CO_2 reported by individual measurement is slightly smaller (or higher) than the value published in a national standard while the value of SO_2 is identical.

9.4.5 Reproducibility

This measure describes the qualitative assessment of the extent to which information about the methodology and data values allows an independent practitioner to reproduce the results reported in the study. This quality measure is used when some form of public claim is to be made regarding the results of a study. Anti-trust legislation may also exclude the attainment of the level of transparency needed to satisfy its use in the public arena.

9.4.6 Identification of anomalies/missing data

Anomalies are extreme data values within a data set. These values are normally identified through statistical analysis and/or as the result of expert review. Whenever anomalies or missing data are identified and either removed from the data set or replaced by a calculated value, they are identified in the study report. These data values may exist as a result of misinterpreted requests for data input, misreported data values, improper analysis of data samples or simply not available.

The anomalies are identified during a comprehensive review of each data category for each unit process. The anomalies are returned to the reporting location or internal company experts to determine their validity for inclusion in the database. Where the anomaly is explained in terms of a process upset or accidental release, they can be retained in the data set. The decision should be made according to the goal and scope of the study. If an explanation cannot be found or a reporting error cannot be corrected, the anomaly is removed from the data set and properly documented.

Once the anomalies are dealt with, missing data are evaluated to determine the appropriate inputs for individual data categories. A basic guideline is that each data category for each reporting location shall have one of the followings:

— an acceptable reported data value;

— a zero value where applicable;

— a calculated value based on the average of reported values;

— values from unit processes with similar technology.

10 Examples of performing sensitivity analysis

A sensitivity analysis assesses the influence on the final results of the changes in input parameter or decision, one at a time. Sensitivity analysis in life cycle inventory is a necessary step due to the inevitable subjectivity in certain decisions made at the onset of the study or during its iterations, as well as the quality elements in the data used. There is need to understand the consequences of these decisions for proper transparency in the study.

10.1 Context of the Standard

ISO 14041 states in 5.3.5 that:

— Where the study is intended to support a comparative assertion made to the public, the final sensitivity analysis of the inputs and outputs data shall include the mass, energy and environmental relevance criteria, as outlined in this subclause.

in 6.4.5 that:

— Reflecting the iterative nature of LCA, decisions regarding the data to be included shall be based on a sensitivity analysis to determine their significance;

and in 7 that:

— The interpretation shall include a data quality assessment and sensitivity analyses on significant inputs, outputs and methodological choices in order to understand the uncertainty of the results.

10.2 Overview

A sensitivity analysis shall be made when a significant result of the inventory analysis depends on values which are either:

— determined by a choice (e.g. allocation rule);

— within an uncertainty range;

— missing (i.e. data gaps).

A decision should be made concerning those values or parameters to select for testing.

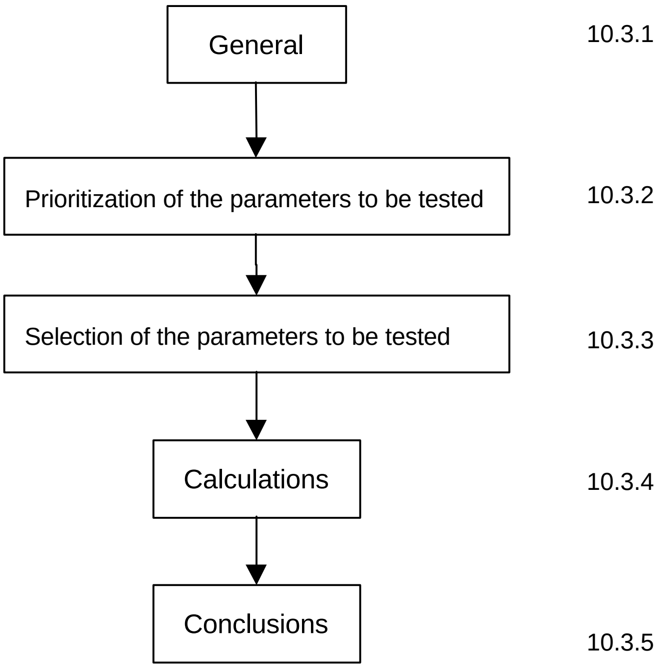


Figure 22 – Overview of the general approach

10.3 Description of the examples

10.3.1 General

Sensitivity analysis can be carried out by changing key parameters of the life cycle inventory analysis and recalculating inventory in order to compare the results to the reference situation. More specifically,

1) introducing parameters corresponding to the key points to be tested,

2) changing those parameters in order to recalculate the inventories for each analysis,

3) evaluating the sensitivity of the parameters by comparing the resulted inventories.

In conducting the sensitivity analysis, some parameters have to be determined to characterize each analysis. The number of calculations depends on the number of sensitivity analysis the user carried out.

The examples of key elements to be considered include:

— the choice of the functional unit;

— uncertainty of data value (inside a range), electricity consumption, transport distance, etc.;

— uncertainty of system boundaries (geographic, time), choice of the electricity production model [e.g. OECD average for 1994, or Statistics of Country-A's Electricity Demand and Supply (1993)], etc.;

— other methodological choices, allocation rules, cut-off rules, recycling rules, avoiding the study of the production step of a non-elementary flow, etc.

The sensitivity analysis may result in:

— the exclusion of life cycle stages or sub-systems when the lack of significance can be shown by the sensitivity analysis,

— the exclusion of material flows which lacks significance to the outcome of the results of the study,

— the inclusion of new units processes that are shown to be significant in the sensitivity analysis.

10.3.2 Prioritization of the parameters to be tested

Sensitivity analyses are performed to test the effect which key assumptions and data variability have on the results of a life cycle inventory study. A common approach to sensitivity analysis is to change the data input for a selected independent variable by plus or minus a defined percentage (e.g. change the fuel oil consumption in a unit process by plus or minus 10 %).

In an attempt to prioritize the independent variables, a variance index may be utilised to determine which of these variables strongly influences the results of the study. The conceptual thinking behind a variance index suggests that four factors may influence the significance that an independent variable has on the results of the study:

— the contribution of the quantity of a unit process data category to the quantity of a product system data category,

— the relative importance of the data category (sensitivity factor),

— the variability of the unit process data to the unit process data category,

— the completeness of the inputs to the data category.

Unit processes with higher percentage contribution have greater influence on the inventory results. Data categories have different environmental effects related to material flows, energy flows and emissions. The precision of a data set is directly correlated to the uncertainty of the inventory results while the completeness of a data set has an inverse correlation.

10.3.3 Selection of the parameters to be tested.

Once the parameters that could be of interest have been prioritised, it is necessary to select the type of sensitivity analysis to be conducted. Once conducted, an interpretation of the results should be provided.

10.3.3.1 Overview of the example

Using as a basis the open-loop recycling example in 8.3.3, a sensitivity analysis could have been conducted to evaluate -- the adequacy of the input parameters, the variability of the data from different locations included in the LCI study or the impact of the chosen allocation procedure.

An examination of these potential types of sensitivity analysis concluded that, because the high level of recycling in the example 8.3.3, the allocation procedure selected, regardless its being in accordance with the standard, deserves further evaluation.

The flow chart in Figure 23 illustrates the steps taken to describe the example.

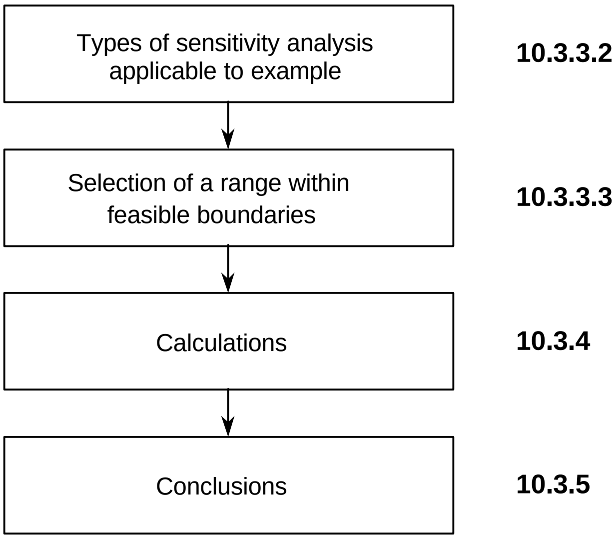


Figure 23 – Steps to describe the example of sensitivity analysis

10.3.3.2 Types of sensitivity analysis applicable to the study

An examination of the example in 8.3.3, for purposes of illustration, indicates that different sensitivity analyses could be justified for the example in question. Regarding the methodological rules or procedures, the allocation in open-loop recycling is certainly an important element because of the chosen value of the allocation factor. In addition, the quality of the data is important - how contemporaneous, how accurate in its collection and aggregation, etc. Further, regardless its quality, since different manufacturing sites were considered, the average values used in the study could reflect substantial variability that needs consideration. Another potential sensitivity analysis could be the range of transportation distances in the distribution of the primary product.

These and other situations should be analysed towards the end of the study. In practical cases more than one sensitivity analysis will be performed. For the sake of brevity we selected a sensitivity analysis on the allocation procedures. There are other reasons for the selection of the allocation procedures. An examination of the formulae and the specific allocation procedure- based on number of uses- reveal that the allocation factor could vary significantly at higher recycling levels and according to the number of uses.

The data on which the recycling rates for the primary product and for other co-products were based on well established and accepted national statistics, both by the paper industry and the government agencies. Regardless, a sensitivity analysis on the procedure itself should be made because of its importance.

10.3.3.3 Selecting a range of values within feasible boundaries

The procedure described in example open-loop recycling of 8.3.3, according to ISO 14041, estimates an allocation factor for the primary product and the totality of the subsequent uses which is ultimately, a function of the number of uses and the fraction of the original product being recycled in other systems.

Allocation Factor, $F = f(u, z_1)$

The F for the primary (original) product was estimated as 0,6146. Assuming realistic combined variability of +25% and -25%, an extreme range of plausible F values could be 0,76 and 0,46.

10.3.4 Calculations

A complete iteration of all the results of the study for these two extreme conditions is not necessary, as the basic values for all the results were not shown in 8.3.3. Suffice to say that the results will not be directly proportional to the new values since specific differences will occur in different stages of the product system according to the extreme factors.

A broad, generalized view of the consequences in the basic results from the extreme assumptions made for the sensitivity analysis is given in the following table. With the exception of specific parameters considered in the study (the result of the practitioner's mastery of its study), the following results would help in the analysis and in determining the need for further sensitivity analysis on the components of the allocation factor.

Table 7 – Consequences in different values for *F*

ELEMENTS	0,46 *F*	0,61 *F*	0,76 *F*
Functional unit:			
Mass of product used	100	100	100
Recycling rate, z_1	[a]	0,70	[a]
Mass of recycled product		70	
Number of uses, u	[a]	2,225	[a]
Burdens or loadings:			
Staying with primary prod.	0,46	0,6146	0,76
Pass on to Secondary prod.	0,54	0,3854	0,24
Amount produced/100 used	54	38,54	24,0
Variation from base (0,61)	15,46	0	14,54

[a] Different combination of values possible since $F = f(u, z_1)$

10.3.5 Conclusions

The appropriateness of conducting a sensitivity analysis on the allocation procedures is indicated by the results anticipated in Table 7. This variability is significant enough to be indicated to the readers of the study. In our specific case, it also justifies further analysis.

Since F is function of both the number of uses and the recycling rates, it could be proper to conduct separate analyses on each one of them which would have indicated, in the case of the example in 8.3.3 that the recycling rate fraction is the most sensitive of the two elements making up the allocation factor.

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