
Environmental management — Life cycle assessment — Illustrative examples on how to apply ISO 14044 to goal and scope definition and inventory analysis

Management environnemental — Analyse du cycle de vie — Exemples illustrant l'application de l'ISO 14044 à la définition de l'objectif et du champ d'étude et à l'analyse de l'inventaire



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Published in Switzerland

Contents

Page

Foreword	v
Introduction.....	vi
1 Scope	1
2 General	1
3 Examples of developing functions, functional units and reference flows	3
3.1 Context of ISO 14044.....	3
3.2 Overview.....	3
3.3 Identification of functions.....	5
3.4 Selection of functions and definition of functional unit.....	5
3.5 Identification of performance of the product and determination of the reference flow.....	6
3.6 Additional examples.....	6
4 Examples of distinguishing functions of comparative systems	6
4.1 Context of ISO 14044.....	6
4.2 Overview.....	7
4.3 Identification and selection of functions	8
4.4 Equivalence of reference flows.....	9
4.5 Adjusting for performance differences	10
5 Examples of establishing inputs and outputs of unit processes and system boundaries	11
5.1 Context of ISO 14044.....	11
5.2 Overview.....	12
5.3 Determining the product system's unit processes and their boundaries.....	12
5.4 Initial collection of data at each unit processes.....	15
5.5 Initial estimate of material and energy flows.....	16
5.6 Applying decision rules.....	18
5.7 Inputs, outputs and system boundaries established	19
6 Examples of avoiding allocation.....	19
6.1 Context of ISO 14044.....	19
6.2 Overview.....	20
6.3 Example of allocation avoidance by dividing the unit process to be allocated into two or more processes	21
6.4 Example of allocation avoidance by expanding the boundaries for comparison of systems with different outputs	21
7 Examples of allocation.....	23
7.1 Context of ISO 14044.....	23
7.2 Overview.....	24
7.3 Description of the examples	24
8 Example of applying allocation procedures for recycling	27
8.1 Context of ISO 14044.....	27
8.2 Overview.....	28
8.3 Description of the examples	29
9 Examples of conducting data quality assessment	38
9.1 Context of ISO 14044.....	38
9.2 Overview.....	39
9.3 Data requirements to establish the specific listing of sites.....	40
9.4 Requirements to characterize the quality of the data.....	41

10 Examples of performing sensitivity analysis.....43

10.1 Context of ISO 14044 43

10.2 Overview 43

10.3 Description of the examples.....44

Bibliography 48

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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 2.

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.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

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

This second edition cancels and replaces the first edition (ISO/TR 14049:2000), which has been technically revised.

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 14044 and this Technical Report, is 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 ISO 14044:2006, based on several examples on key areas of ISO 14044 in order to enhance the understanding of the requirements of ISO 14044.

With respect to the various phases of LCA, methodological requirements for conducting LCA studies are provided in ISO 14040 and ISO 14044.

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Environmental management — Life cycle assessment — Illustrative examples on how to apply ISO 14044 to goal and scope definition and inventory analysis

1 Scope

This Technical Report provides examples about practices in carrying out a life cycle inventory analysis (LCI) as a means of satisfying certain provisions of ISO 14044:2006. These examples are only a sample of the possible cases satisfying the provisions of ISO 14044. They offer “a way” or “ways” rather than the “unique way” for the application of ISO 14044. These examples reflect only portions of a complete LCI study.

2 General

The examples focus on six key areas of ISO 14044:2006 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 ISO 14044 and with the specific use.

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

- context of ISO 14044;
- overview;
- description of the examples.

Table 1 — Cross references between ISO 14044:2006 and examples in this Technical Report

ISO 14044:2006	Examples in this Technical Report
0 Introduction	
1 Scope	
2 Normative reference	
3 Terms and definitions	
4 Methodological framework for LCA	
4.1 General requirements	
4.2 Goal and scope definition	
4.2.1 General	
4.2.2 Goal of the study	
4.2.3 Scope of the study	
4.2.3.1 General	
4.2.3.2 Function and functional unit	3 Examples of developing functions, functional units and reference flows
	4 Examples of distinguishing functions of comparative systems
4.2.3.3 System boundary	5 Examples of establishing the inputs, outputs and boundary of unit process
	10 Examples of performing sensitivity analysis
4.2.3.4 LCIA methodology and types of impacts	
4.2.3.5 Types and sources of data	5 Examples of establishing the inputs, outputs and boundary of unit process
4.2.3.6 Data quality requirements	9 Examples of conducting data quality assessment
4.2.3.7 Comparisons between systems	4 Examples of distinguishing functions of comparative systems
4.2.3.8 Critical review considerations	
4.3 Life cycle inventory analysis (LCI)	
4.3.1 General	
4.3.2 Collecting data	
4.3.3 Calculating data	
4.3.3.1 General	9 Examples of conducting data quality assessment
4.3.3.2 Validation of data	
4.3.3.3 Relating to unit process and functional unit	3 Examples of developing functions, functional units and reference flows
4.3.3.4 Refining the system boundary	10 Examples of performing sensitivity analysis
4.3.4 Allocation	
4.3.4.1 General	6 Examples of avoiding allocation
4.3.4.2 Allocation procedure	7 Examples of applying allocation
4.3.4.3 Allocation procedures for reuse and recycling	8 Examples of applying allocation procedures for recycling
4.4 Life cycle impact assessment (LCIA)	
4.5 Life cycle interpretation	
5 Reporting	
5.1 General requirements and considerations	
5.2 Additional requirements and guidance for third-party reports	
5.3 Further reporting requirements for comparative assertion intended to be disclosed to the public	
6 Critical review	
6.1 General	
6.2 Critical review by internal or external expert	
6.3 Critical review by panel or interested parties	
Annex A (informative)	
Annex B (informative)	Example of a data collection sheets
	Examples of life cycle interpretation

3 Examples of developing functions, functional units and reference flows

3.1 Context of ISO 14044

ISO 14044:2006, 4.2.3.2, states:

"The scope of an LCA shall clearly specify the functions (performance characteristics) of the system being studied. 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 chosen the functional unit, the reference flow shall be defined."

ISO 14044:2006, 4.2.3.3, states:

"An appropriate flow shall be determined for each unit process. The quantitative input and output data of the unit process shall be calculated in relation to this flow. Based on the flow chart and the flows between unit processes, the flows of all unit processes are related to the reference flow. The calculation should result in all system input and output data being referenced to the functional unit".

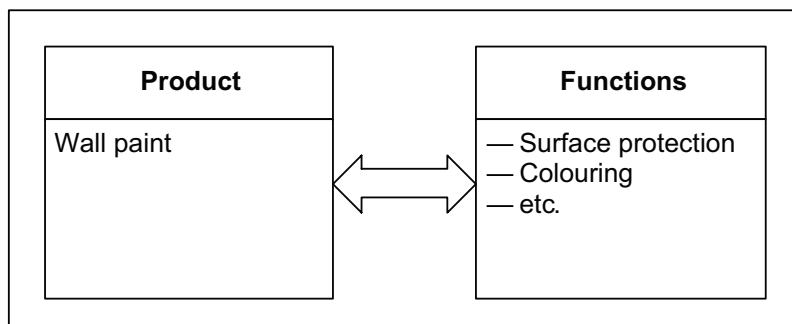
3.2 Overview

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

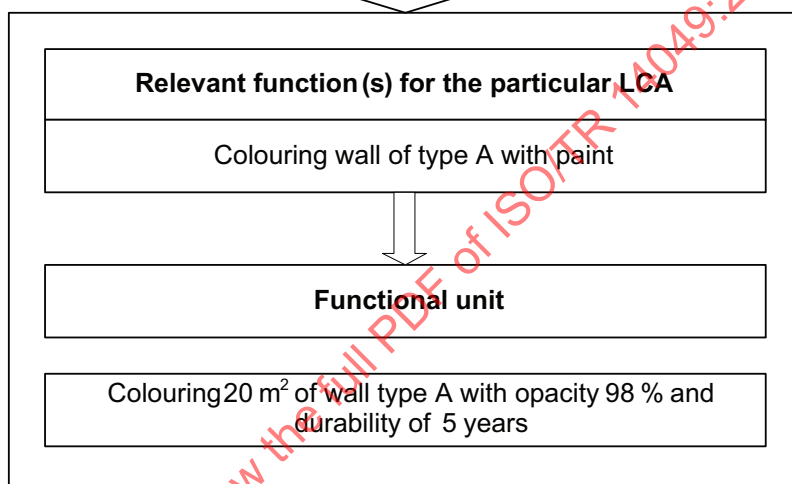
- identification of functions;
- selection of functions and definition of functional unit;
- identification of performance of the product and determination of the reference flow.

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.

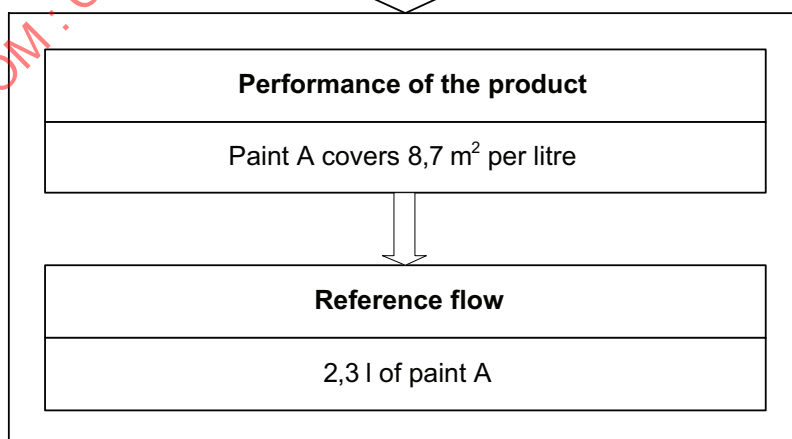
**3.3
Identification of functions**



**3.4
Selection of functions and
definition of functional unit**



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



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 are 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 typically needs to specify the area to be covered (e.g. 20 m²), 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 m² 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 m² 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 m² 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 in Table 3 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 ISO 14044

ISO 14044:2006, 4.2.3.2 and 4.2.3.7, addresses situations dealing with product systems with one or more functions and the requirement that comparisons of systems be done with the same functional unit.

ISO 14044:2006, 4.2.3.2, states:

"Having chosen the functional unit, the reference flow shall be defined. Comparisons between systems shall be made on the basis of the same function(s), quantified by the same functional unit(s) 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 explained and documented. As an alternative, systems associated with the delivery of this function may be added to the boundary of the other system to make the systems more comparable. In these cases, the processes selected shall be explained and documented."

ISO 14044:2006, 4.2.3.7, states:

"In a comparative study, the equivalence of the systems being compared shall be evaluated before interpreting the results. Consequently, the scope of the study shall be defined in such a way that the systems can be compared. Systems shall be compared using the same functional unit and equivalent methodological considerations, such as performance, system boundary, data quality, allocation procedures, decision rules on evaluating inputs, and outputs and impact assessment. Any differences between systems regarding these parameters shall be identified and reported. If the study is intended to be used for a comparative assertion intended to be disclosed to the public, interested parties shall conduct this evaluation as a critical review."

4.2 Overview

When comparing product systems, special attention should be paid 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 clause, some possible approaches are described and illustrated by examples.

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

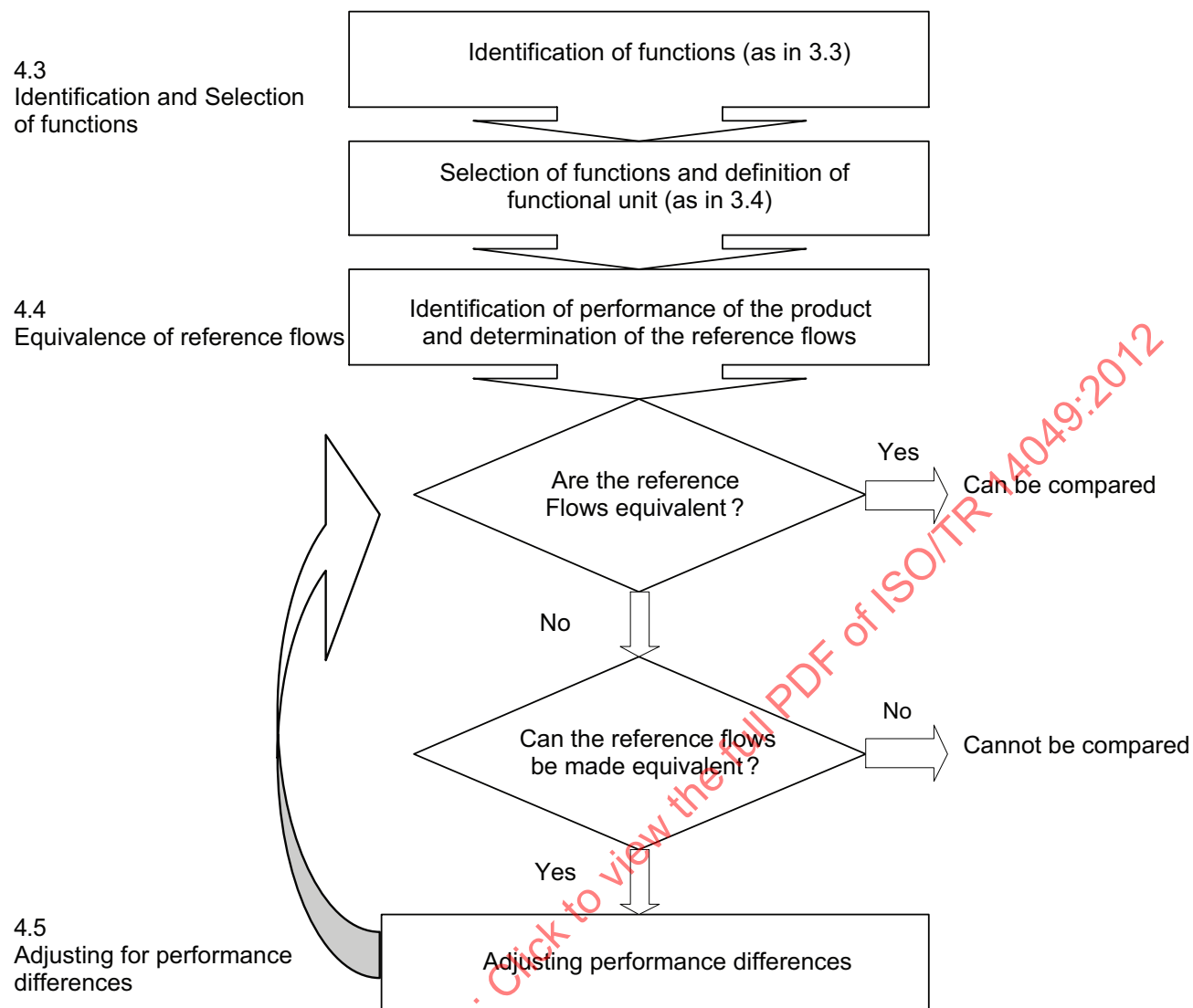


Figure 2 — Overview of the steps in comparative studies

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 should be paid 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 packaging 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 m² 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 are calculated based on a test using standard conditions, concerning e.g. surface type and opacity.

The standardised test conditions and measurement methods should 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 is 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 decreases 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 typically takes 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 are 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 subclause, 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 be 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 involves 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 are somehow 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:

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

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 may 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 ISO 14044

ISO 14044:2006, 4.2.3.3 provides guidelines for the following:

a) the selection of the system boundary consisting with the goal and scope of the study (4.2.3.3.1)

"The system boundary determines which unit processes shall be included within the LCA. The selection of the system boundary shall be consistent with the goal of the study. The criteria used in establishing the system boundary shall be identified and explained."

Decisions shall be made regarding which unit processes to include in the study and the level of detail to which these unit processes shall be studied."

b) the use of a process flow diagram describing each process involved (4.2.3.3.2)

"Ideally, the product system should be modelled in such a manner that inputs and outputs at its boundary are elementary and product flows. It is an iterative process to identify the inputs and outputs that should be traced to the environment, i.e. to identify which unit processes producing the inputs (or which unit processes receiving the outputs) should be included in the product system under study. The initial identification is made using available data. Inputs and outputs should be more fully identified after additional data are collected during the course of the study, and then subjected to a sensitivity analysis (see ISO 14044, 4.3.3.4)."

and

c) the cut-off criteria for the inclusion and exclusion of inputs and outputs (4.2.3.3.3)

Several cut-off criteria are used in LCA practice to decide which inputs are to be included in the assessment, such as mass, energy and environmental significance. Making the initial identification of inputs based on mass contribution alone may result in important inputs being omitted from the study. Accordingly, energy and environmental significance should also be used as cut-off criteria in this process.

- 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.
- d) **Energy:** similarly, an appropriate decision, when using energy as a criterion, would require the inclusion in the study of those inputs that cumulatively contribute more than a defined percentage of the product system's energy inputs.
- e) **Environmental significance:** decisions on cut-off criteria should be made to include inputs that contribute more than an additional defined amount of the estimated quantity of individual data of the product system that are specially selected because of environmental relevance.

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 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.

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.

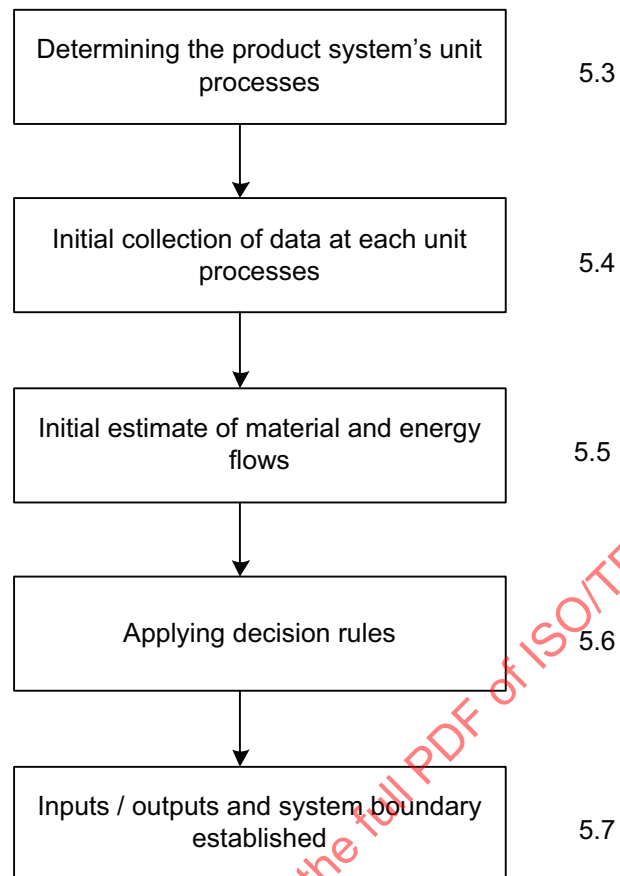


Figure 3 — Overview of establishing inputs, outputs and system boundaries

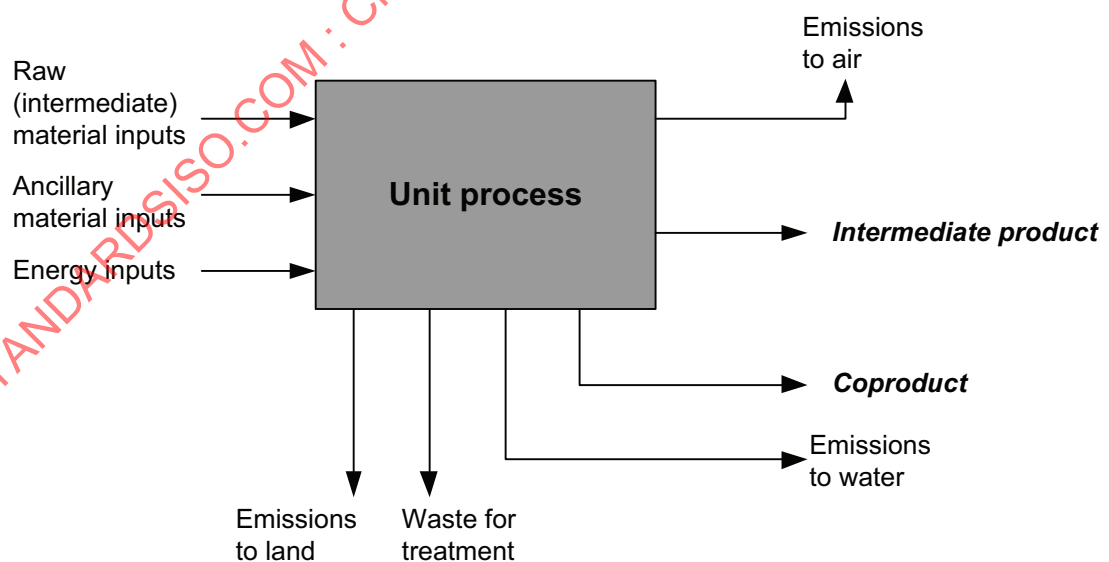


Figure 4 — Conceptual example of unit process description

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

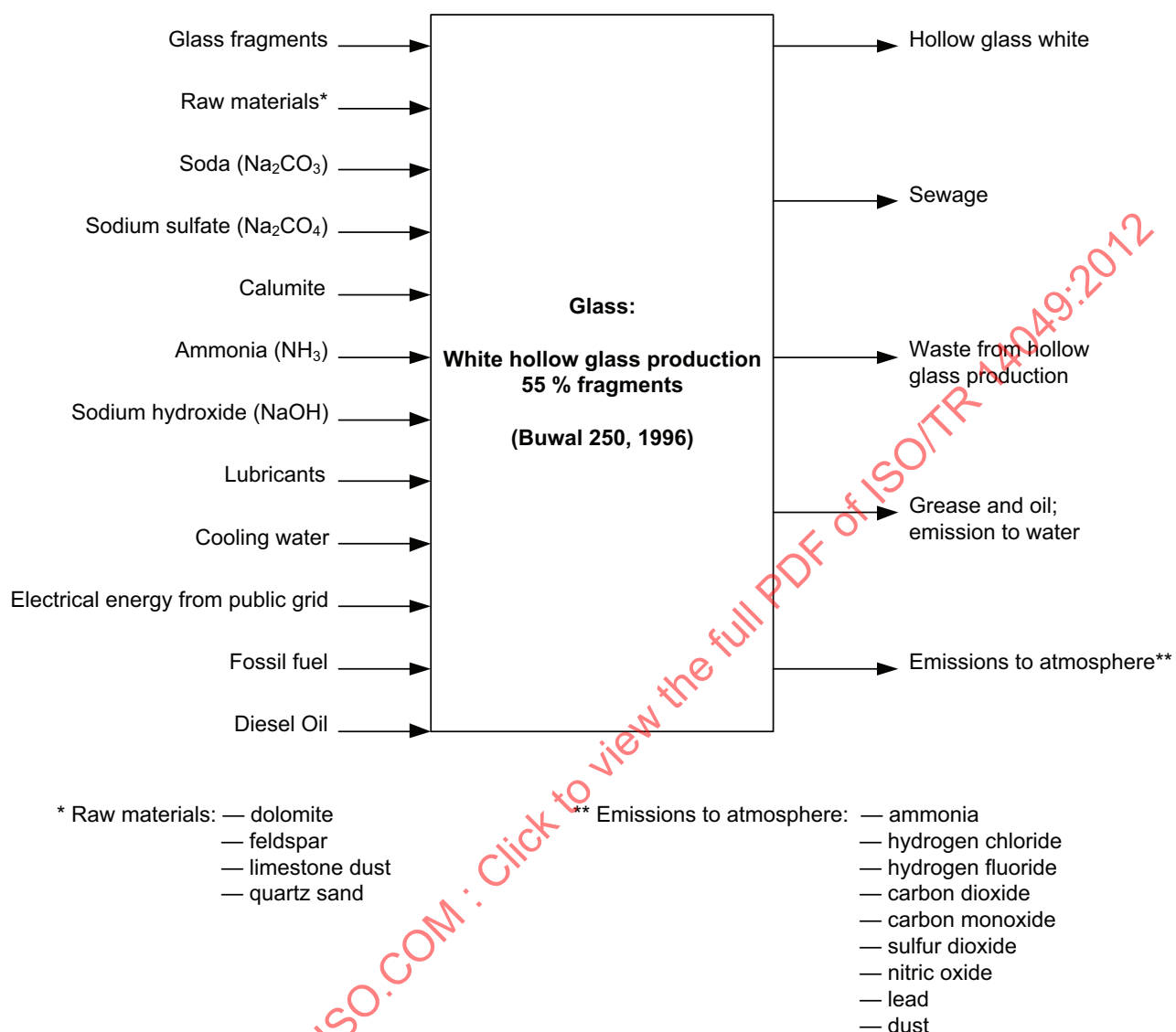


Figure 5 — Example of unit process description for white hollow glass production (1 of 2)

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	M^3	1,70
Electrical energy from public grid (Swiss)	Intermediate product	$\text{kW}\cdot\text{h}$	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	M^3	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 (2 of 2)

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 should 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 x 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	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	145,0
Soap ^b	0,5 kg	145,5
Sodium sulphate	0,06 kg	145,56
Hypochlorite	0,05 kg	145,61
Roller oil	0,048 kg	145,658
Chlorine	0,030 kg	145,688
Sodium chlorate	0,030 kg	145,718
Oxygen	0,030 kg	145,748
Tin ^b	0,025 kg	145,773
Anthracite coal	0,020 kg	145,793
Sulfur dioxide	0,020 kg	145,813
Not specified	0,012 kg	145,825
Peroxide	0,005 kg	145,83
Hydrogen	0,002 kg	145,832
Cobalt oxide	0,002 kg	145,834
Total	145,8 kg	
+ Printing ink and colours ^b no data available		
+ Water	7 000 l	
^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 5 % to the mass inputs of a unit process or those that contribute less than 1 % 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 is 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 can 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 can be that the sum of all processes included is 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 ISO 14044

For allocation procedures, ISO 14044:2006, 4.3.4.1, states in general terms:

"The inputs and outputs shall be allocated to the different products according to clearly stated procedures that shall be documented and explained together with the allocation procedure."

The sum of the allocated inputs and outputs of a unit process shall be equal to the inputs and outputs of the unit process before allocation. Whenever several alternative allocation procedures seem applicable, a sensitivity analysis shall be conducted to illustrate the consequences of the departure from the selected approach."

ISO 14044:2006, 4.3.4.2, states:

“The study shall identify the processes shared with other product systems and deal with them according to the stepwise procedure presented below.

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

- 1) *dividing the unit process to be allocated into two or more sub-processes and collecting the input and output data related to these sub-processes, or*
- 2) *expanding the product system to include the additional functions related to the co-products, taking into account the requirements of 4.2.3.3.*

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 that reflects the underlying physical relationships between them; i.e. they should 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 that reflects other relationships between them. For example, input and output data might be allocated between co-products in proportion to the economic value of the products.*

Note : formally step 1 is not part of the allocation procedure.

6.2 Overview

This clause presents two examples for avoiding allocation that exemplifies the flexibility in applying the specific guidance of ISO 14044:2006. The two examples in 6.3 and 6.4 are depicted in Figure 6.

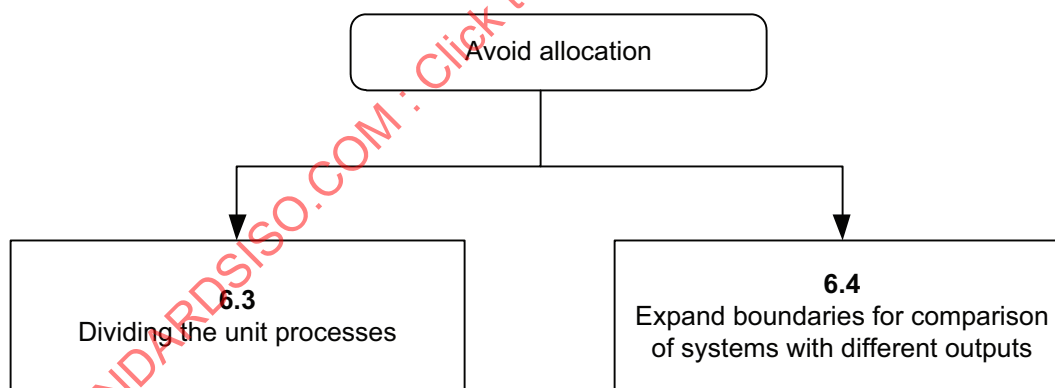


Figure 6 — Overview of examples for avoiding allocation

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).

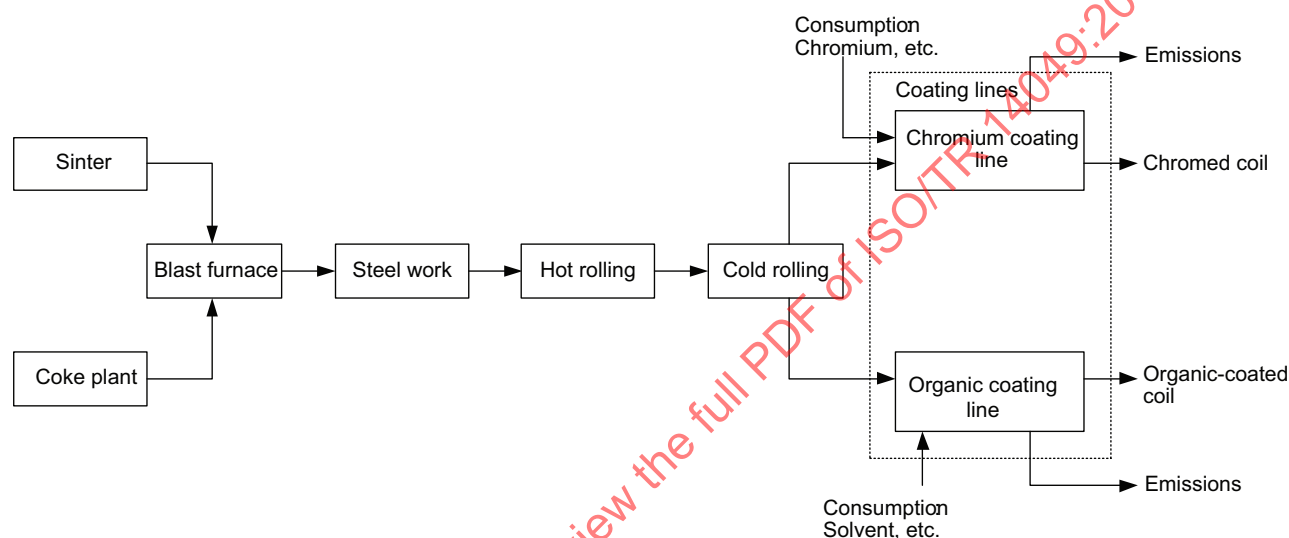


Figure 7 — System where allocation may be avoided through a more precise data collection and dividing into two different subsystems

In this case, if data collection encompasses both chromium and organic coating, it is 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 co-product, plastic film. The other option includes energy recovery and produces heat as a co-product. 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.

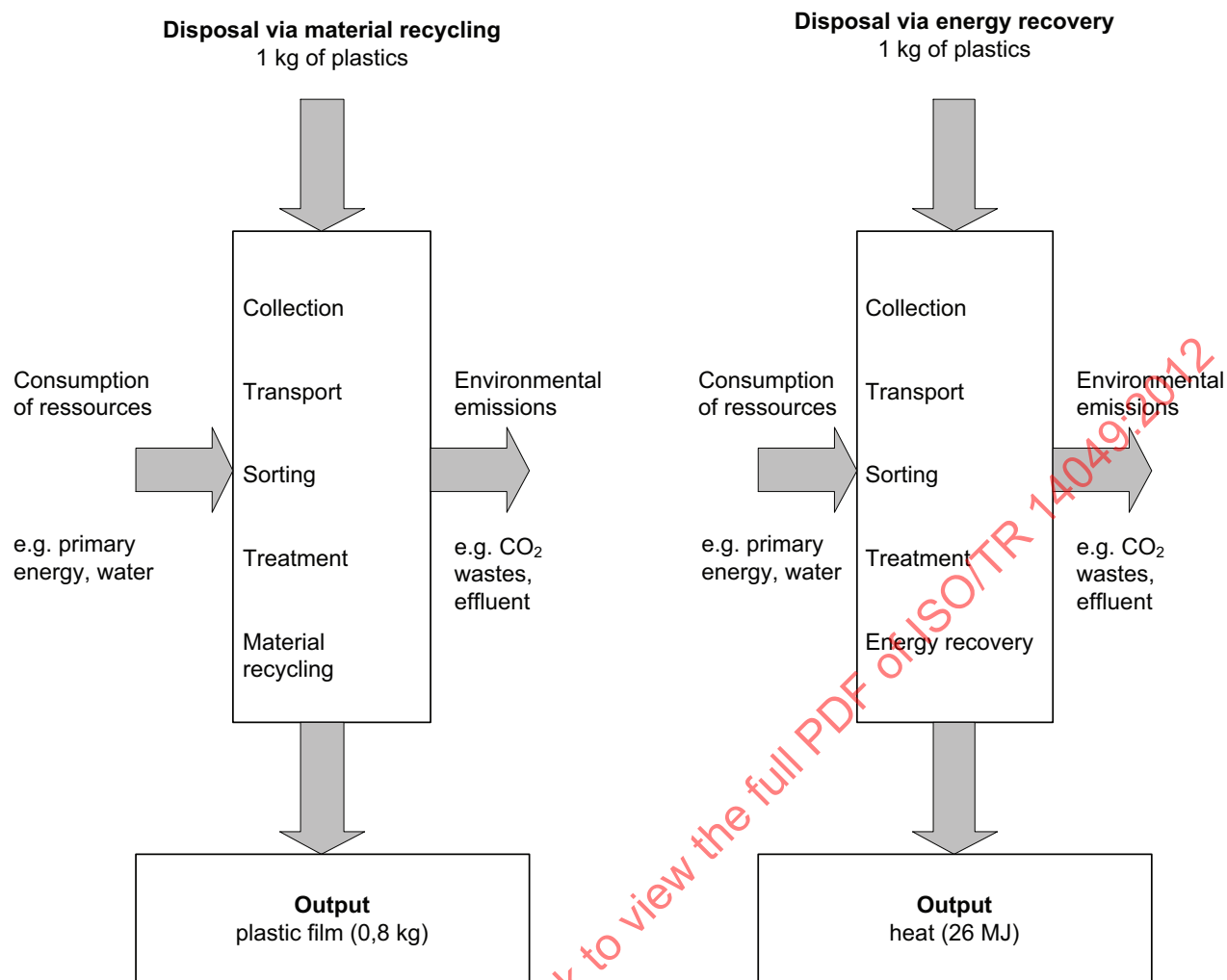


Figure 8 — Example of material recycling and energy recovery

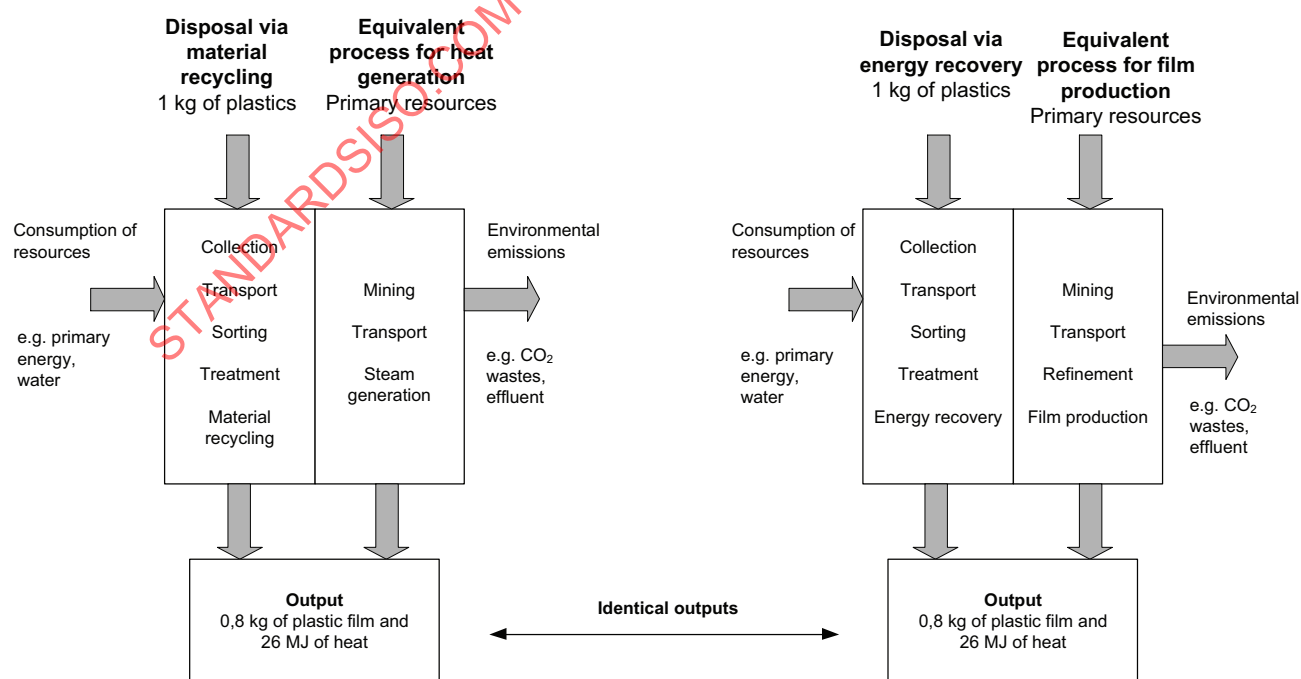


Figure 9 — Example of an expansion of the system boundaries

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 are 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 do 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 in the following, regarding technology coverage.

7 Examples of allocation

7.1 Context of ISO 14044

For allocation procedures, ISO 14044:2006, 4.3.4.2, states:

“The study shall identify the processes shared with other product systems and deal with them according to the stepwise procedure presented below.

- a) **Step 1:** *Wherever possible, allocation should be avoided by*
 - 1) *dividing the unit process to be allocated into two or more sub-processes and collecting the input and output data related to these sub-processes, or*
 - 2) *expanding the product system to include the additional functions related to the co-products, taking into account the requirements of 4.2.3.3.*
- b) **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 that reflects the underlying physical relationships between them; i.e. they should reflect the way in which the inputs and outputs are changed by quantitative changes in the products or functions delivered by the system.*
- c) **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 that reflects other relationships between them. For example, input and output data might be allocated between co-products in proportion to the economic value of the products.*

Note: formally step 1 is not part of the allocation procedure.

7.2 Overview

The two selected examples are presented according to the prescribed stepwise procedure of ISO 14044:2006, 4.3.4.2, 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. Subclause 7.3.2 of this Technical Report provides an example where a physical relationships to allocate is not available and a purely economic way is adopted.

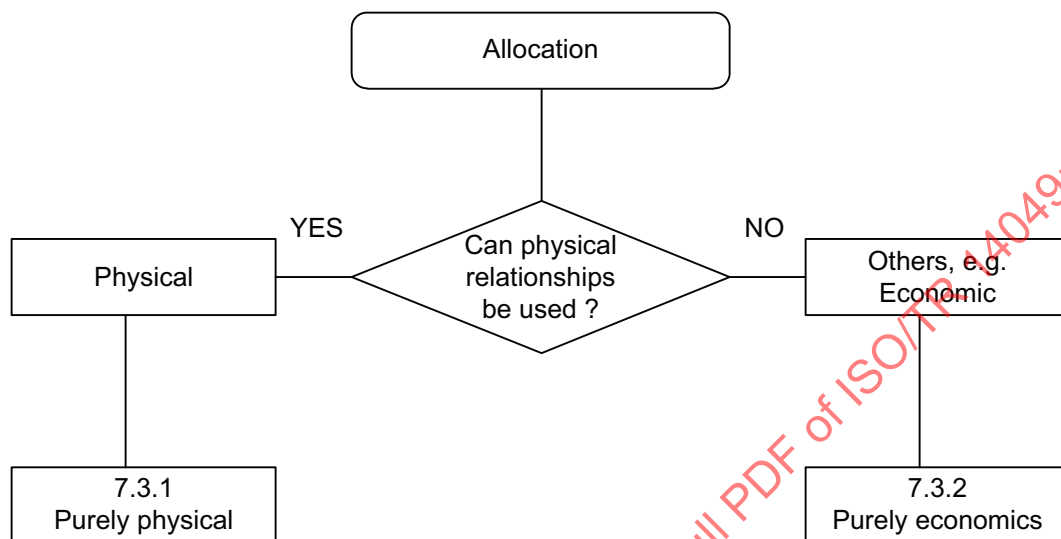


Figure 10 — Overview of examples for allocation procedure

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 simplicity¹⁾, 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.

1) Any simplification needs to be justified to avoid its misuse.

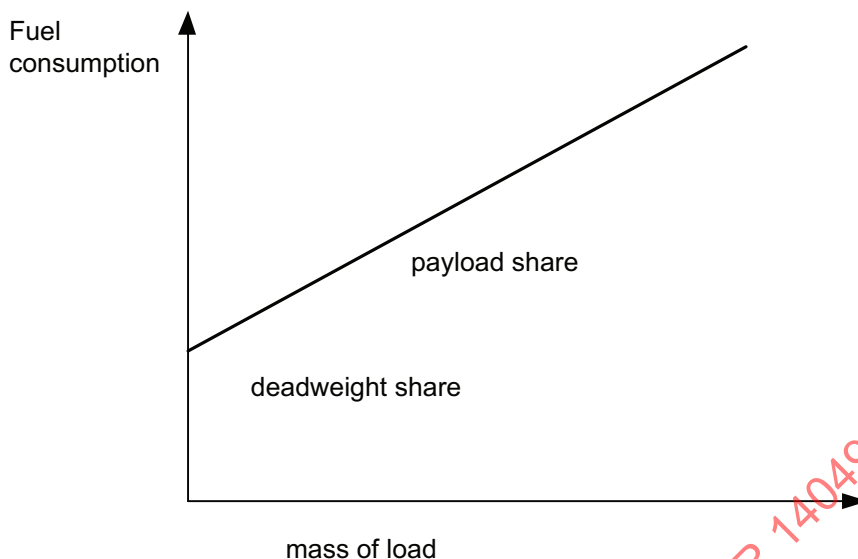


Figure 11 — Fuel consumption of a truck in dependence on the load transported

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 of all, it is important to check whether the truck is used up to mass capacity or volume capacity, and to determine the share of the package. 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:

- a) **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.
- b) **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. 40 % of the truck capacity are consumed by 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 simplicity²⁾, 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.

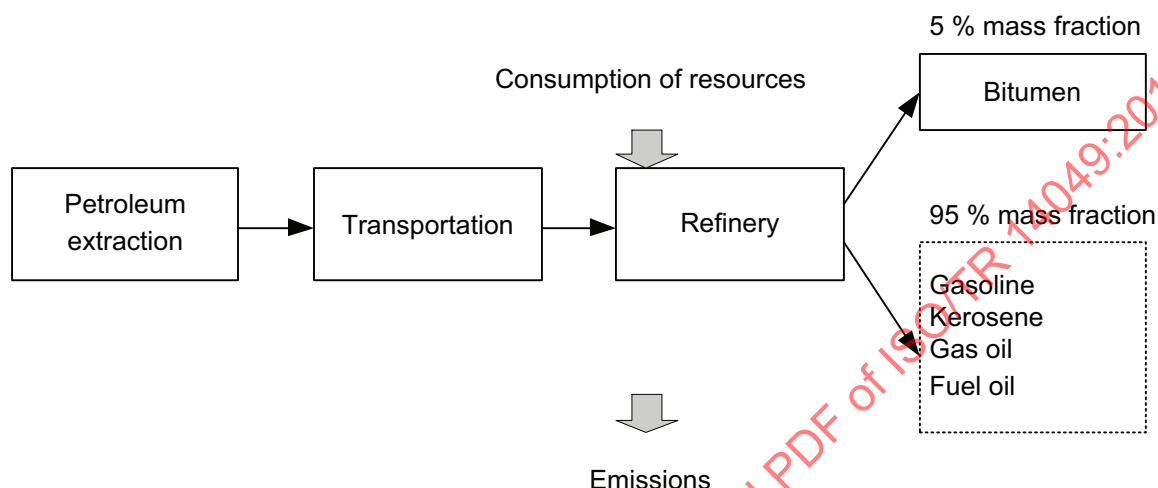


Figure 12 — Example of bitumen production process

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

Therefore, an allocation factor F needs 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 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 14044, these physical relationships 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.

This procedure fails in this example 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.

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.

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

Therefore, the third choice proposed in ISO 14044, 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 $\{D_j\}$ is 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 $\{D_j\}$.

8 Example of applying allocation procedures for recycling

8.1 Context of ISO 14044

For recycling, ISO 14044:2006, 4.3.4.3.1, states:

— the allocation principles and procedures in 4.3.4.1 and 4.3.4.2 also apply to reuse and recycling situations.

ISO 14044:2006, 4.3.4.3.2, states:

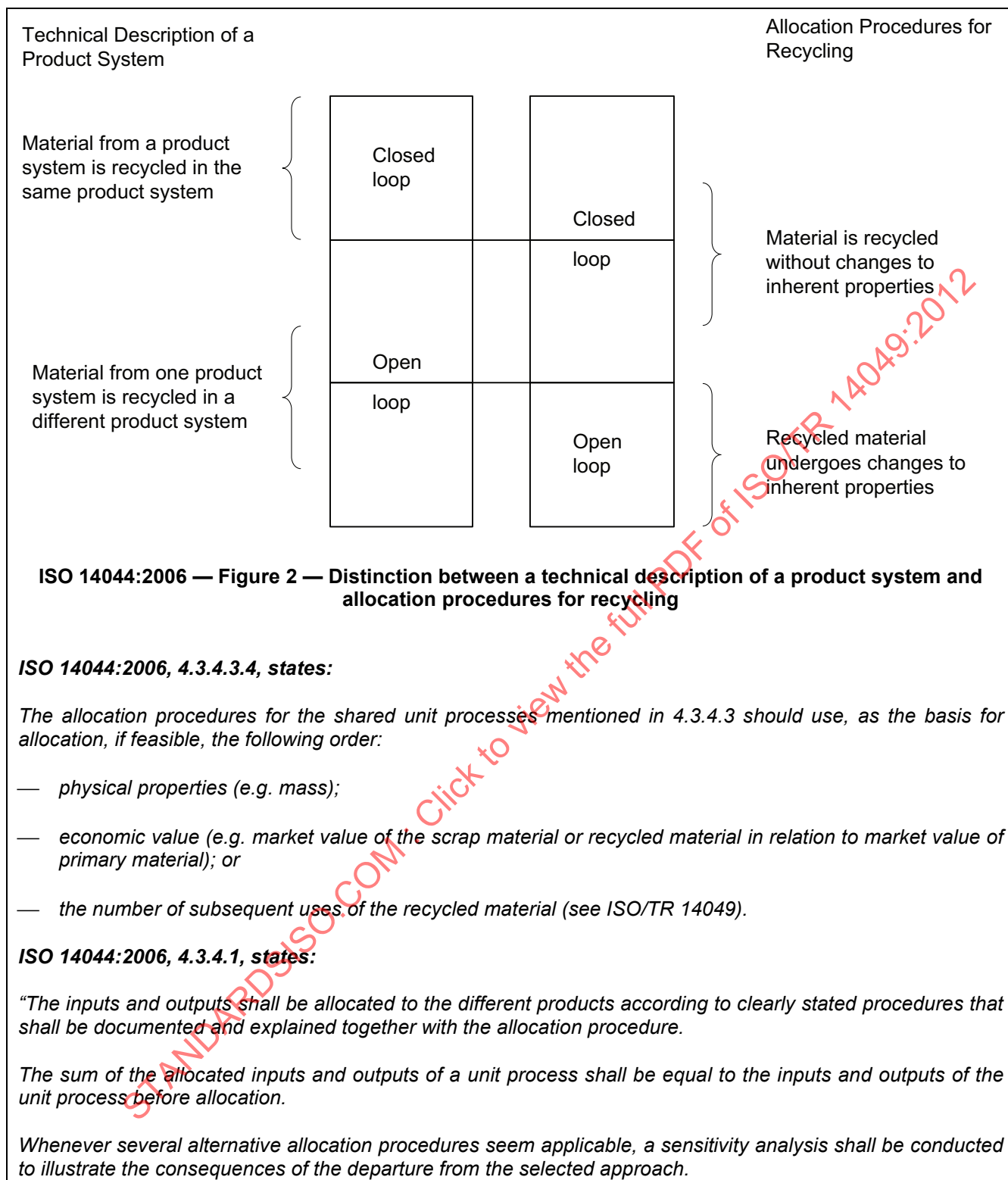
However, these situations require additional elaboration for the following reasons:

- 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.

Further, ISO 14044:2006, 4.3.4.3.3, states:

Several allocation procedures are applicable for reuse and recycling. The application of some procedures is outlined conceptually in Figure 2 and is distinguished in the following to illustrate how the above constraints can be addressed.

- a) 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 in b).
- b) 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.



This applies particularly for the recovery processes between the original and subsequent product system.

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.

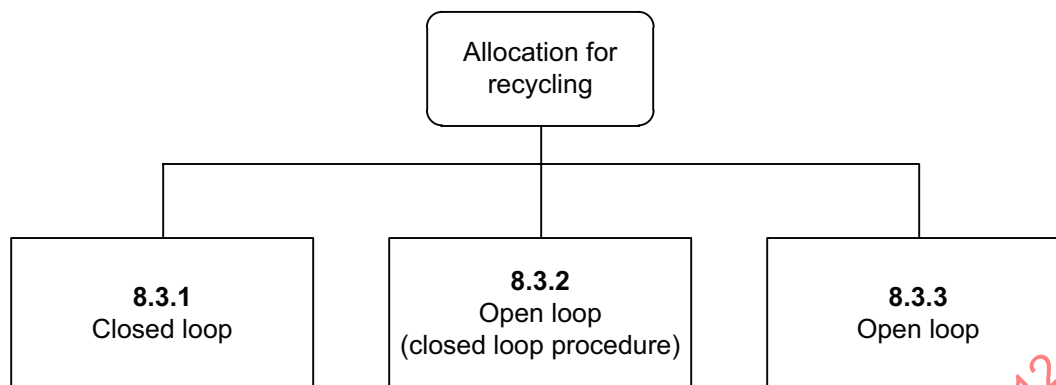


Figure 13 — Overview for examples for recycling

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.

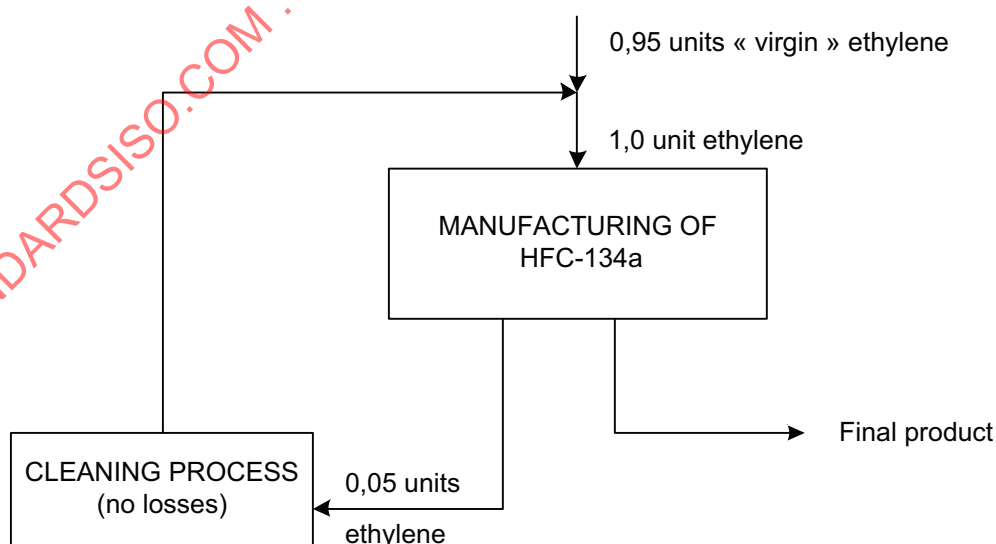


Figure 14 — Flow diagram of closed loop recycling example

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 is 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.

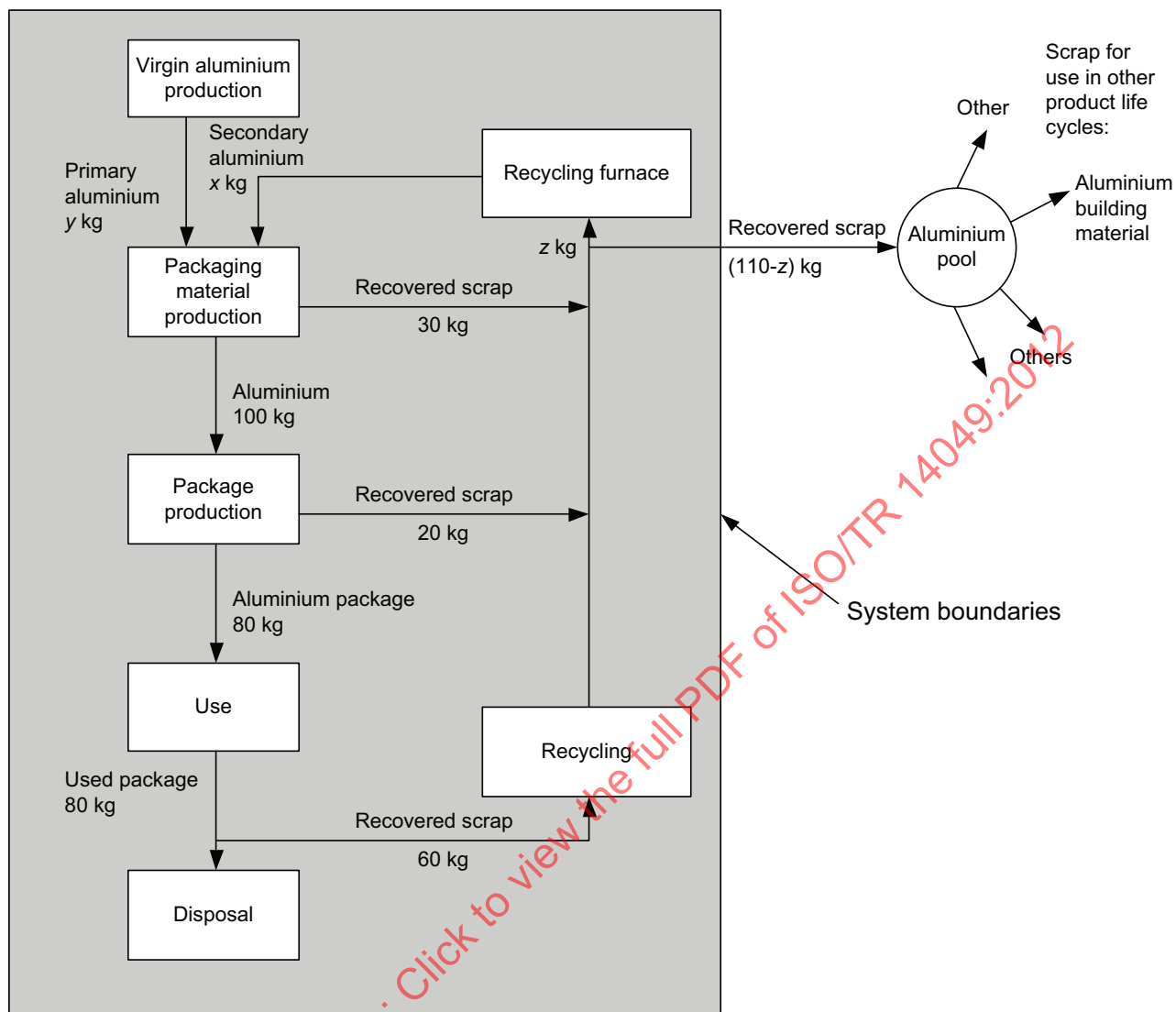


Figure 15 — Open-loop with closed-loop recycling procedure for aluminium package (fictitious numbers)

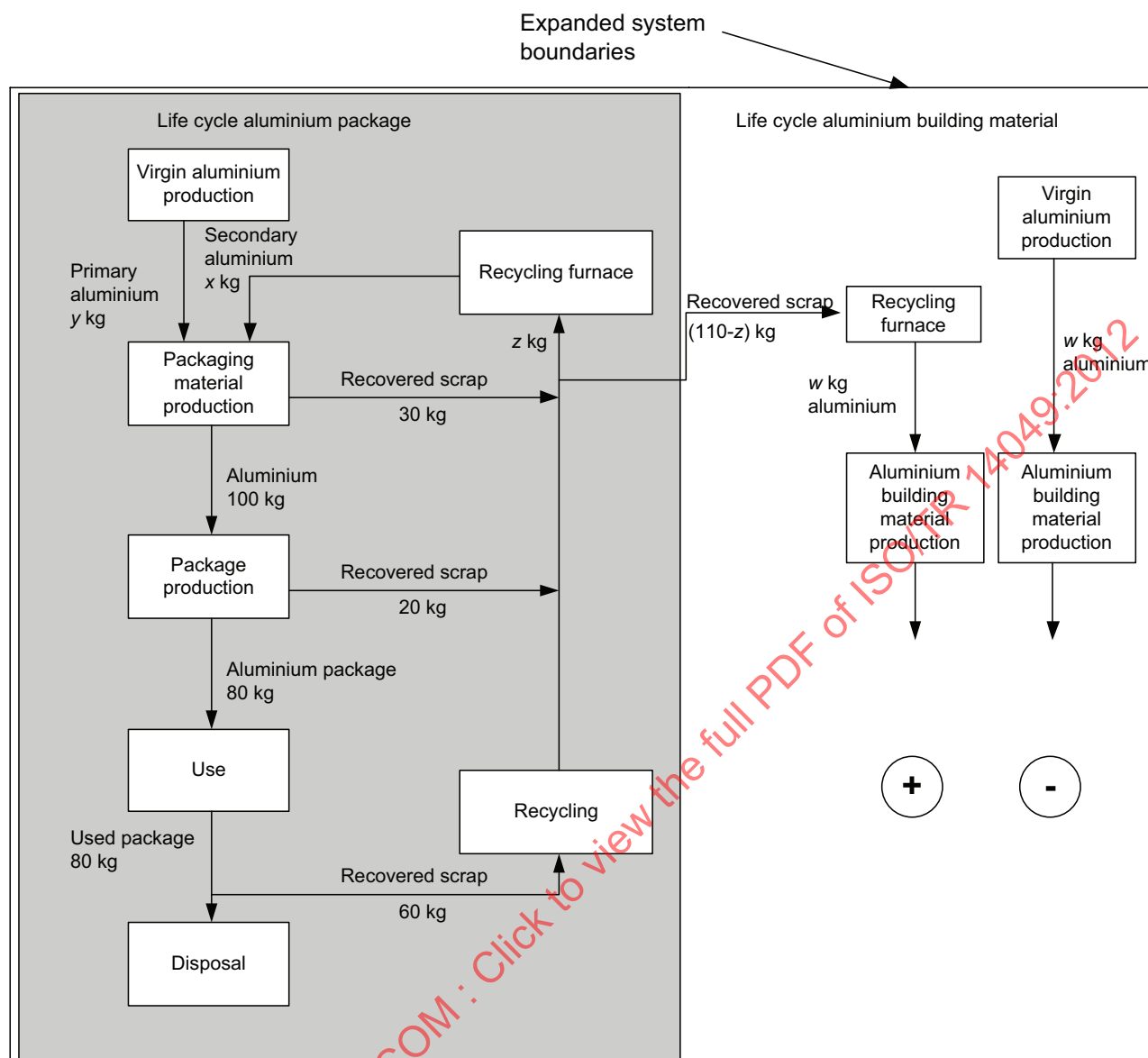


Figure 16 — Open-loop with closed-loop recycling procedure for aluminium package with expanded system boundaries (example for other product life cycles: aluminium building material)

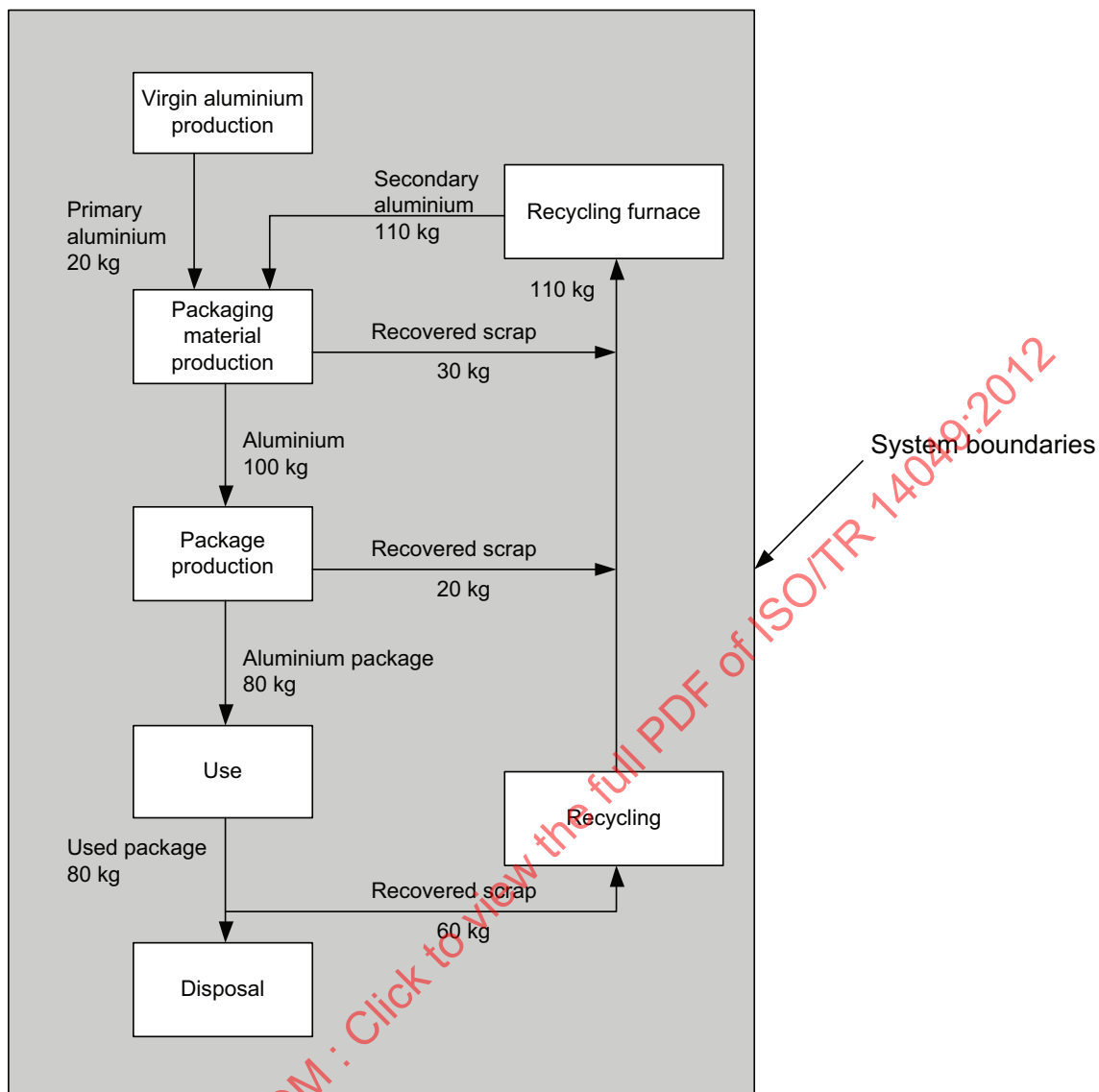


Figure 17 — Closed loop recycling model for aluminium package with an adjusted product-specific technology split

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.

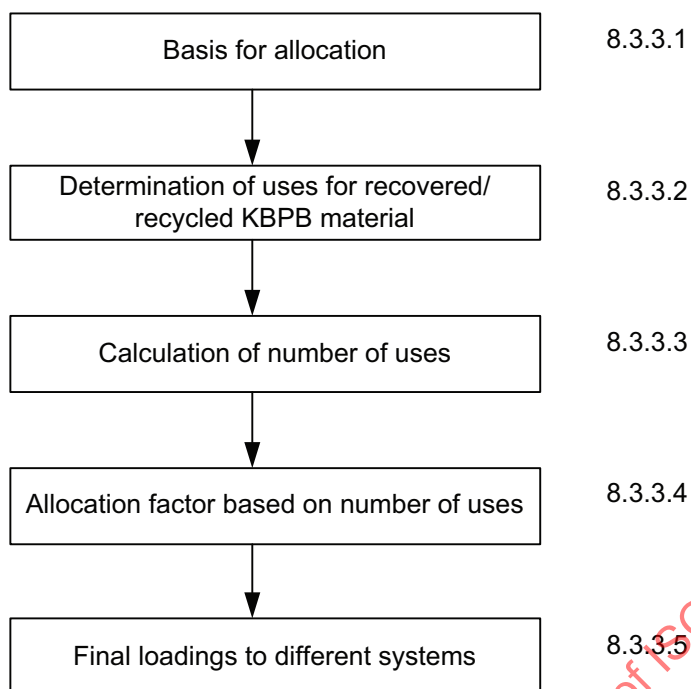


Figure 18 — Steps to describe the example of open loop recycling

8.3.3.1 Basis for allocation

The “basis” on which the allocation factor is made — that is, the total loading which is 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.

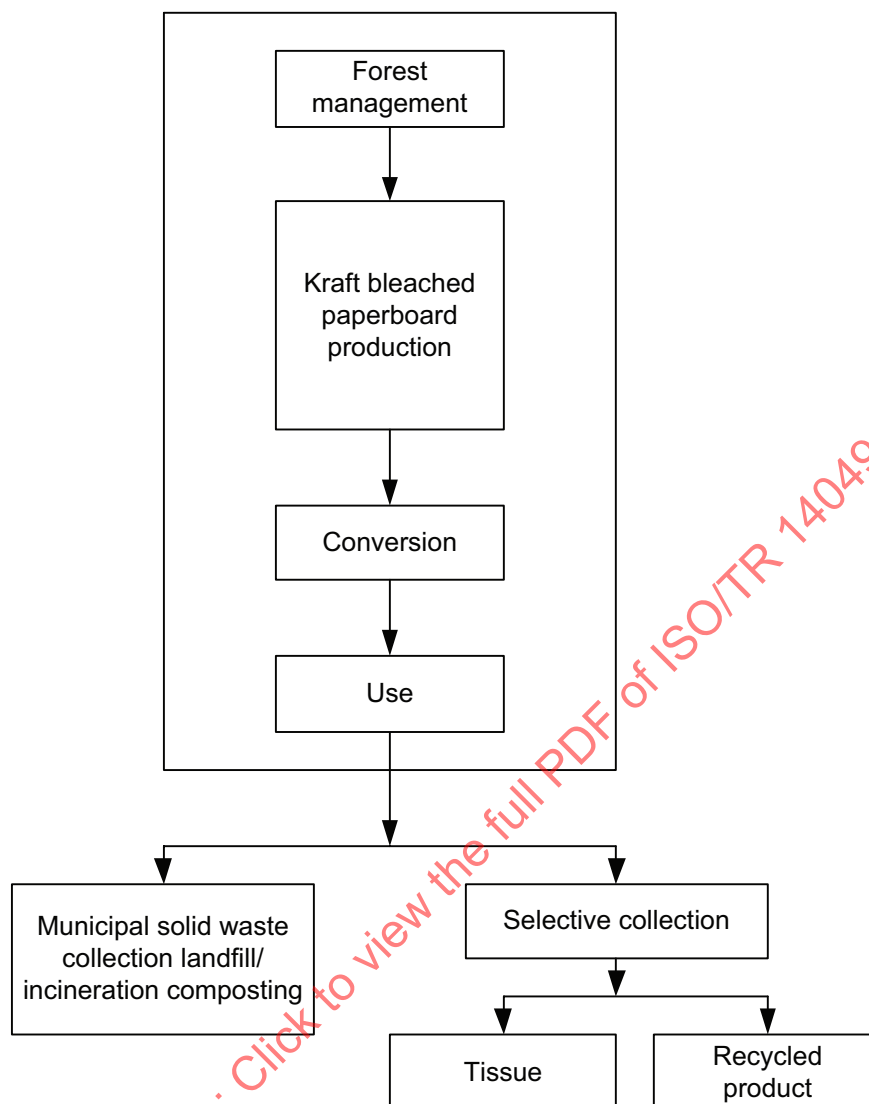
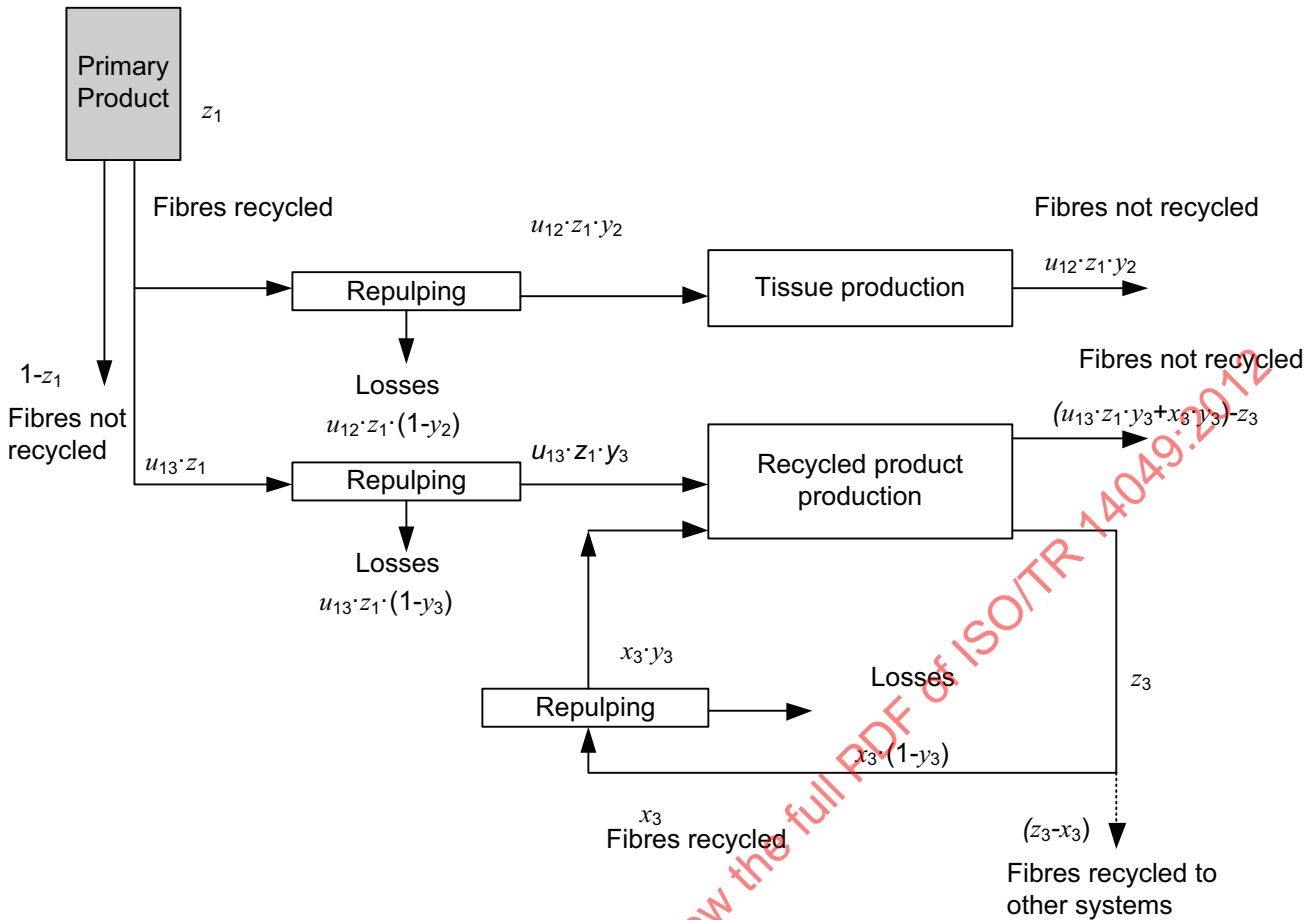


Figure 19 — Allocation basis

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.



$$z_1 = 0,70, u_{12} = 0,25, u_{13} = 0,75, z_3 = x_3 = 0,5, y_2 = y_3 = 1,0$$

Figure 20 — Different uses of the discarded and recovered KBPB products

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 8.3.3.3. 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:

$$\begin{aligned}
 u &= 1 && \text{(first use of the primary product recycled)} \\
 &+ z_1 \cdot u_{12} \cdot y_2 && \text{(tissue use)} \\
 &+ z_1 \cdot u_{13} \cdot y_3 && \text{(recycled product use; the first pass)} \\
 &+ z_1 \cdot u_{13} \cdot y_3 \cdot (z_3 \cdot y_3) && \text{(recycled product use; the second pass)} \\
 &+ z_1 \cdot u_{13} \cdot y_3 \cdot (z_3 \cdot y_3)^2 && \text{(recycled product use; the third pass)} \\
 &\dots\dots\dots \\
 &+ z_1 \cdot u_{13} \cdot y_3 \cdot (z_3 \cdot y_3)^{n-1} && \text{(recycled product use; the } n\text{th pass)}
 \end{aligned}$$

or,

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

Calculating the last element and grouping results in:

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

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 is remembered that the primary (original) material also shares on this fraction. The final loading allocation factor for the primary (original) product system is 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 receives, 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 needs 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 takes place and once used it is discarded, the allocation factor remains 0,3854 for that recycled “raw material” fibre in use.

For the other recycled paper product system, the allocation factor of 0,3854 that comes 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 is 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 is similar to the one already described in the above. Again, it is important that the assumptions and calculations on the allocation factor is 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 ISO 14044

ISO 14044:2006, 4.2.3.6.2, states:

The data quality requirements should address the following:

- a) *time-related coverage: age of data and the minimum length of time over which data should be collected;*
- b) *geographical coverage: geographical area from which data for unit processes should be collected to satisfy the goal of the study;*
- c) *technology coverage: specific technology or technology mix;*
- d) *precision: measure of the variability of the data values for each data expressed (e.g. variance);*