Impact Assessment

PEAS 2022 — 2023

Next two lectures

- nov. 30: general definitions and discussion of LCA and other intensity metrics
- dec. 1: cheeseburgers

INTRODUCTION

The reduction of the environmental impact of products, processes, or services requires evaluation of their environmental performance.

Life cycle assessment (LCA) is the most widely used tool to evaluate the environmental impact of any activity, including food production systems.

LCA evaluates the environmental impact at each stage of the production of food: cradle to grave.

LCAs for food products usually include all the steps in the production chain until the product reaches the consumer, but they can also include home preparation and final disposal of residues.

LCA

In essence, the conduction of a LCA is the application of mass and energy balances on a particular process, product, or service and includes all energy and raw material as *inputs* and the environmental wastes as *outputs*.

LCAs do not incorporate into the analysis important environmental effects such as biodiversity, the landscape, and the local impact of water use

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Consider canned green beans….

The basic process for production of canned green beans consists of filling metal cans with clean, sorted, and trimmed green beans that are then covered with brine, closed, commercially sterilized, labeled, and packed in secondary containers.

These containers are then palleted and sent to distributions centers.

So in a first layer of analysis, the materials needed to make canned green beans are green beans, metal cans and lids, salt, water, cardboard boxes, pallets, and miscellaneous items such as glue, plastic films, and labels.

Energy requirements include electricity to run the canning plant and natural gas for steam production.

Effluents and emissions primarily include wastewater, solid waste from the sorting and cleaning, and air emissions.

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Consider canned green beans….

An LCA should consider energy, materials, and wastes produced at every single step of the process

This would also include the impacts involved during production of green beans in the fields, construction of cans, and the production of labels, cardboard boxes, and plastic films, just to mention a few.

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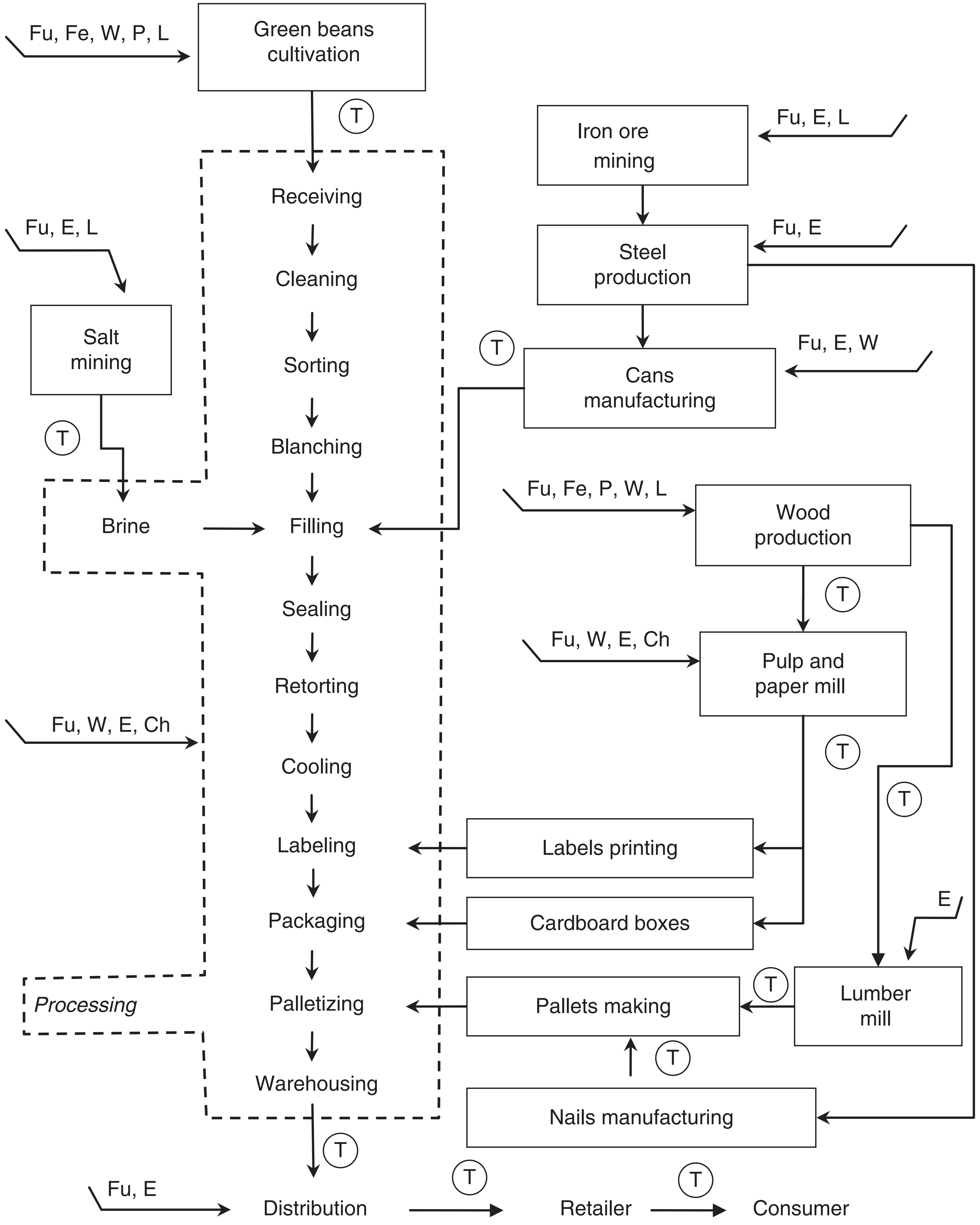
Consider canned green beans….

Depending on the depth of the analysis, LCAs can be classified into three different orders.

The simplest is one in which only materials and transport are included is called a *first-order approach* to LCA and it is hardly ever used.

In a *second-order approach*, all environmental impacts are considered, including production of electricity, fuel for machinery and transport, chemical additives, pesticides, fertilizers, herbicides, ingredients, and water.

In a *third-order approach*, all capital goods are included in the analysis. For the canned green beans example, it would include such things as the impact of manufacturing farming equipment, trucks, the canning plant, the pulp and paper mill, and equipment for salt mining operations.



Fu: Fuel
P: Pesticides
E: Electricity
Fe: Fertilizer
L: Land
T: Transportation
W: Water
Ch: Chemicals

Consider canned green beans….

At this time, there are no requirements for companies to provide consumers with information on the environmental impact of products or services.

However, pressure is increasing from consumers and nongovernmental organizations about the impact of products and services.

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Problems with LCA

As seen in the case of the canned green beans, conducting an LCA is a time-consuming process that translates into a cost measure for a company.

If the analysis is done by the company, or a consultant that has a stake in the product or service, then the results are tinted with a shadow of doubt about the objectivity of the data used in the process.

For that reason, more transparent LCAs come from universities or independent nonprofit organizations with no economical links with the company.

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Problems with LCA

Another limitation of LCAs is that the results depend on where the analyses are conducted.

Different research groups in the same or different regions of the world will produce diverse results depending on assumptions made, estimation of inputs and outputs, and methodology used.

Conveniently, variation in the methodology can be minimized by following standard procedures such as the one described by the **ISO 14040**.

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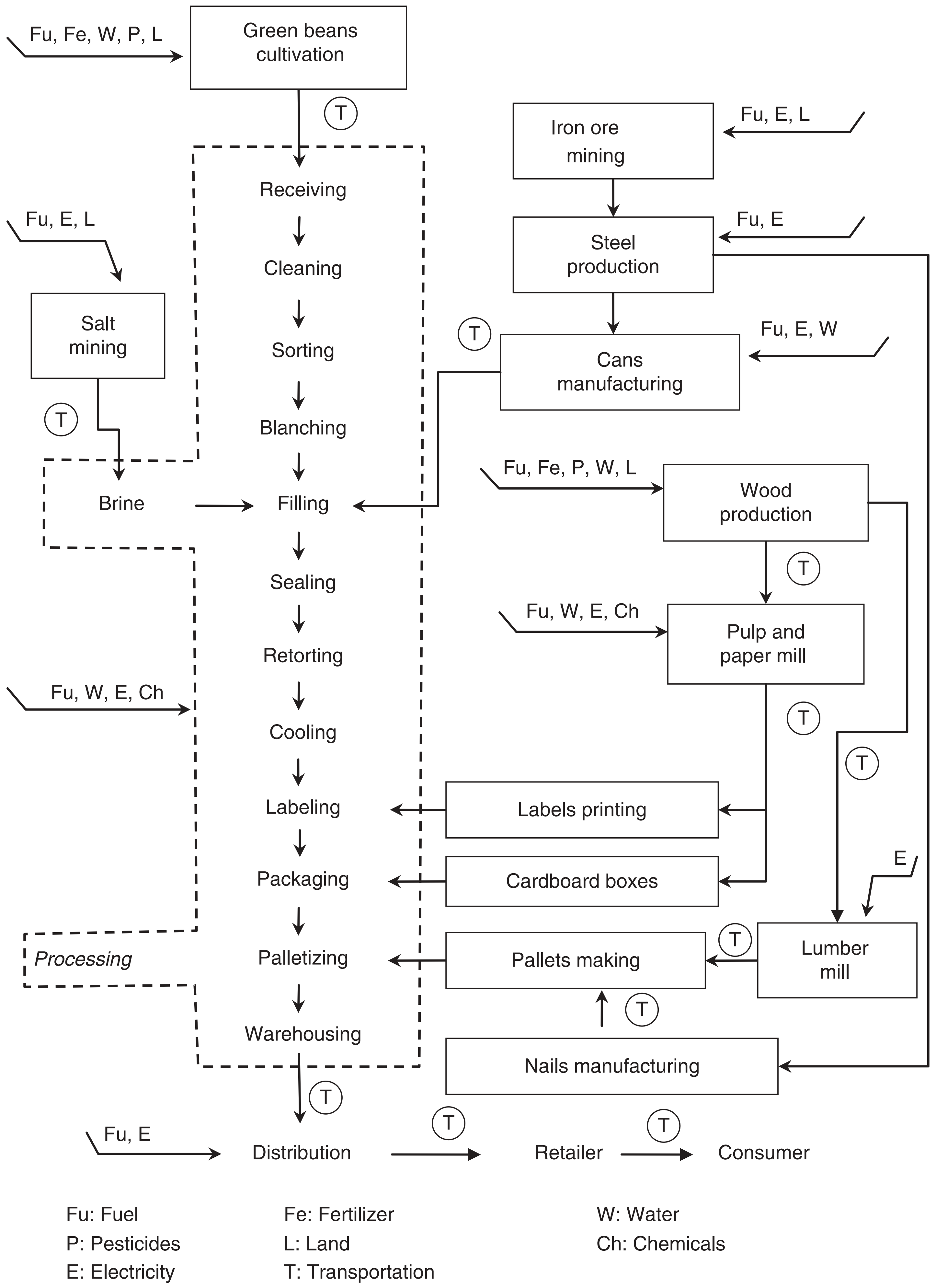
Conducting LCAs using ISO standards

Principles are basically the same: an assessment of all the materials, energy, and wastes produced by each step in the production of raw materials, manufacturing, distribution, and final disposal of a product.



ISO 14000

Currently the mainstream guidelines to conduct LCAs for any product, including food products, are the standards provided by the International Organization for Standardization (ISO), which developed the **ISO 14000 family** that provides specifications for the creation of environmental managements systems.

The ISO 14000 family contains two norms, ISO 14040:2006 and 14044:2006, that prescribe the methodology to conduct LCAs for any product, process, or service.

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Table 4.1 ISO 14000 collection of standards for life cycle assessment.

ISO 14040:2006	Environmental management—Life cycle assessment—Principles and framework
ISO 14044:2006	Environmental management—Life cycle assessment—Requirements and guidelines
ISO/TR 14047:2003	Environmental management—Life cycle impact assessment—Examples of application of ISO 14042
ISO/TS 14048:2002	Environmental management—Life cycle assessment—Data documentation format
ISO/TR 14049:2000	Environmental management—Life cycle assessment—Examples of application of ISO 14041 to goal and scope definition and inventory analysis
ISO Guide 64:1997	Guide for the inclusion of environmental aspects in product standards
ISO/TR 14062:2002	Environmental management—Integrating environmental aspects into product design and development

ISO 14000

The ISO 14040 (ISO, 2006a) divides LCA studies in four phases:

1. Definition of goal and scope.
2. Life cycle inventory analysis.
3. Life cycle impact assessment.
4. Life cycle interpretation.

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1. Definition of goal and scope

The definition of the goal states

1. the intended application of the LCA,
2. the reasons for carrying the study,
3. the intended audience,

whether the results are planned to be used in comparative declarations that will be disclosed to the public.

The definition of the scope comprises the product or system to be studied, the functional unit, the system boundary, the allocation procedures, assumptions, limitations, and so on.

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1. Definition of goal and scope

LCAs are conducted on a base, which is called a *functional unit*.

For instance, a six-pack of beer, 1L of beer, or a beer keg all represent functional units that can be used to conduct an LCA on the production of beer.

1. Definition of goal and scope

Once the functional unit is defined, the next step is to define the **system boundaries**, which will depend on the goal and scope.

If the goal is to study the environmental impact of beer production from ingredients - cultivation to disposal of used containers - then the boundary has to encompass all steps in the process.

1. Definition of goal and scope

However, if the interest is only limited to understanding the impact of the processing part, then the boundaries are set just around the brewery.

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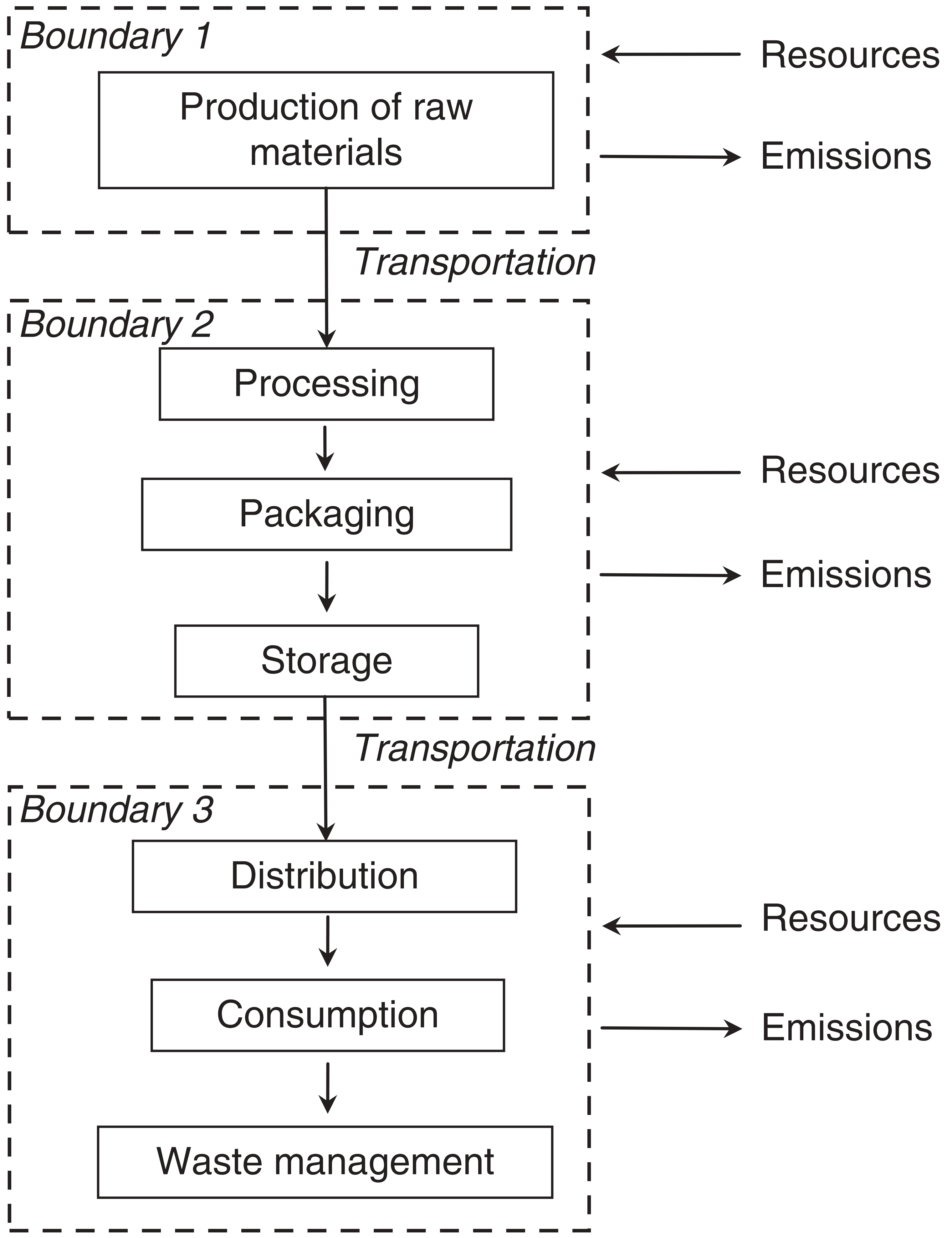

2. Life Cycle Inventory Analysis

Next step is making an inventory of all inputs and outputs that are relevant to the system and are in the set boundary.

Inputs in data collection are renewable and nonrenewable energy, raw materials, water, and so on.

Outputs include products; co-products; environmental releases to air

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2. Life Cycle Inventory Analysis

Once the inputs and outputs are identified, their magnitude in numerical terms needs to be established.

Sources of data include: meter readings from equipment, equipment operating logs or journals, industry data reports, results from laboratory testing, industry databases, government documents, journals, papers, books, trade associations reports and, best engineering judgment.

2. Life Cycle Inventory Analysis

During this step, data needs to be validated and expressed in terms of the functional unit that was defined during goal-and-scope setting.

In the case of energy, all sources, such as fuels and electricity, need consideration, including efficiencies and losses.

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2. Life Cycle Inventory Analysis

Generally, the results of the inventory analysis are presented in a table that contains all the inputs and outputs of different processes encompassed by the boundaries.

Have a close look at pasta.

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Unit process	Inputs	Specific emissions
Durum wheat production (7.4 tons of wheat, which is the average yield in 1 hectare)	Wheat seeds 200 kg Atrazine ($C_8H_{14}ClN_5$) 1.5 kg Fertilizer (N) 500 kg as ammonium nitrate and urea Fertilizer (P) 150 kg as diammonium phosphate Truck 127.5 tons × km considering an average trip of 150 km to transport input materials Tractor I (135 kW) for 14 km of plowing Tractor II (80 kW) 42 km for application of fertilizer (three times) Combine harvester for 2 h of harvesting	Ammonia (NH_3) 27.3 kg (air) Nitrogen oxides (NOx) 0.51 kg (air) Nitrous oxide (N_2O) 2.1 kg (air) Atrazine ($C_8H_{14}ClN_5$) 0.6 kg (soil and water) Nitrite (NO_2^-) 2.5 kg (soil and water) Use of land hectare/year

Unit process	Inputs	Specific emissions
Semolina production (6.8 tons of semolina and 2.1 tons of subproducts)	Water 1.5 m3 Durum wheat 9 tons Truck 450 tons × km for an average trip of 50 km to transport wheat from fields Natural gas 17 kg (780 MJ) Electricity 5.8 MWh	Particulate matter (PM 2.5) 1.4 kg Sulfur dioxide (SO_2) 1.5 mg (air) Nitrous oxide (N_2O) 55 mg (air) Carbon monoxide (CO) 12 mg (air) Carbon dioxide (CO_2) 40 kg (air) Hydrocarbons CxHy 8 mg (air) 0.1-ton compostable waste (soil) Land use for industrial facility 28.5 m^2/year

Unit process	Inputs	Specific emissions
Durum wheat pasta production (1,000 kg of durum wheat pasta)	Water 310 L Semolina 1,010 kg Truck 101 tons × km for an average trip of 100 km to transport semolina Heat gas 136 MJ for heat for services Electricity 40 kWh for services Electricity 120 kWh for processing line Natural gas 22 kg (1,012 MJ) for thermal energy for drying Crude oil 17 kg (700 MJ) for thermal energy for drying	Particulate matter (PM) 15 mg (air) Sulfur dioxide (SO_2) 460 mg (air) Nitrogen oxides (NOx) 200 mg (air) Nitrous oxide (N_2O) 78 mg (air) Carbon monoxide (CO) 13.8 mg (air) Carbon dioxide (CO_2) 106 kg (air) Hydrocarbons CxHy 16 mg (air) Water vapor from drying 245 kg (air) Occupation as industrial area 1.5 m^2/year Occupation as rail/road area 0.2 m^2/year

Unit process	Inputs	Specific emissions
Plastic packages production (1,000 kg of plastic packages)	Expandable polystyrene 1,008 kg Ink 8 kg Heat oil 60.7 GJ Electricity 570 kWh	Pentane (C_5H_{12}) 37.4 kg (air) Iron (Fe) 32 mg (water) Ammonium ion (NH_4^+) 19 mg (water) Nitrate (NO_3^-) 16 mg (water) Phosphate (PO_4^{-3}) 259 mg (water) Sulphate (SO_4^{-2}) 207 mg (water) Hydrocarbons CxHy 8 g (water)

Unit process	Inputs	Specific emissions
Cardboard packages production (167 kg of cardboard packages)	Glue 1.6 kg Ink 0.6 kg Cardboard duplex 170 kg Crude oil 1.5 kg (62 MJ) Electricity 26 kWh	Particulate matter (PM) 1.5 mg Sulfur dioxide (SO_2) 40 mg (air) Nitrogen oxides (NOx) 11 mg (air) Nitrous oxide (N_2O) 0.9 mg (air) Carbon emission (CO) 0.4 mg (air) Carbon dioxide (CO_2) 4.8 kg (air) Waste (paper) 5 kg (soil waste)

3. Allocation

Most food processes are not linear, and they may contain multiple inputs and multiple outputs.

For instance, in poultry processing, the main product is meat; however a variety of co-products—feathers, blood, skin, bones, offal, and meat trims—are by-products generated during processing.

These by-products are subsequently transformed into during other products—poultry meals, blood and feather meals, and poultry fat—and used as feed for farm and companion animals.

Therefore, when conducting a life cycle inventory analysis of the production of poultry meat, the environmental burden needs to be proportionally divided between the “center-of-the-plate-cuts” and the by-products.

In LCA terms, the procedure of determining how much of the environmental burden is caused by each process or product when multiple processes or products are present is called allocation

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3. Allocation

ISO 14044:2006 provides guidelines to deal with allocation situations in a three-step procedure (ISO, 2006b)

1. Avoid allocations as much as possible by dividing the process in two or more separate processes with inputs and outputs for each of them; or by “expanding the product system to include the additional functions related to the co-products” taking into account the requirements of reuse and recycling.

2. If allocations cannot be avoided, partition inputs and outputs between their “different products or functions” using “underlying physical relationships between them.” For instance, using relative mass flows or energy densities.

3. When physical relationships cannot be established, the standard recommends the use of other relationships, for instance economic value.

3. Allocation

In most food-production systems, allocations are difficult to avoid, especially when by-products are involved or when there are multiples inputs that are by-products of previous processes.

For instance, in fish farming the feed may contain poultry feather and blood meals, poultry protein meals, corn gluten meal from corn wet-milling, and soybean meal from soybean oil extraction.

Therefore, when conducting an LCA of a fish farm, this presents a challenge because the environmental burden of each of these ingredients needs to be back- calculated to where the by-product was produced

3. Allocation

Multiple allocation criteria are possible. So, when dealing with these systems, the ISO 14044:2006 recommends a **sensitivity analysis** that compares allocations made using different indicators.

A sensitivity analysis is a comparison of allocations performed using different criteria and the selection of one is based on careful examination and weighing of pros and cons for each criteria.

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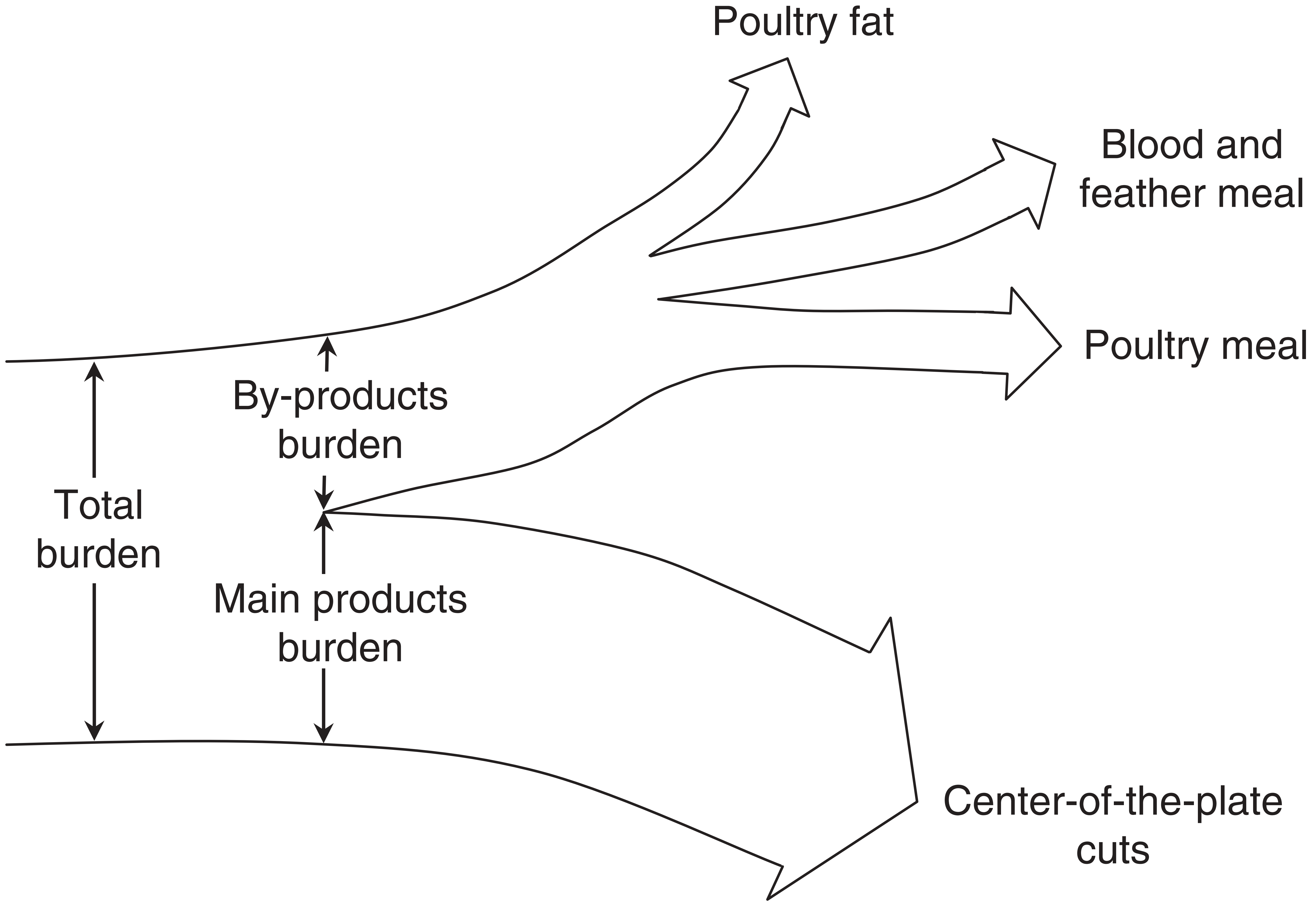
The allocation problem in a life cycle inventory for poultry processing



Total burden = Main products burden + by-products burden

Main products burden = *factor* × Total burden
By-product burden = (1–*factor*) × Total burden

Where the "*factor*", a number less than 1, it is a fractional relationship of underlying physical or economic relationships.

Sensitivity analysis for corn wet mills

Table 4.4 Sensitivity analysis for allocation in the case of corn wet-milling.*

Product or co-product	Mass allocation (%)	Economic allocation (%)	Energy allocation (%)
Corn gluten meal	6.7	10.0	8.9
Corn gluten feed	23.8	8.0	12.8
Corn starch	61.0	78.0	67.3
Corn germ meal	8.5	4.0	11.0

Life Cycle Impact Assessment

In the LCIA, the outcomes of the life cycle inventory (LCI) are analyzed in terms of their potential impact on human health and environmental degradation as well as resource depletion.

The LCIA goal is to connect resource extractions from nature and emissions into nature, which are listed in the LCI, to their potential environmental damages

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Life cycle Impact Assessment

Following the methodology of ISO 14040:2006, the LCIA includes the following steps:

Step 1: selection of impacts

Step 2: classification

Step 3: characterization

Step 4: presentation of data after characterization

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Step one: selection of impacts

The selection of impact categories should be a reflection of the environmental issues related to the product or system being studied and can be done according to two different schools of thought:

1. Classical impact assessment methods, also known as problem-oriented methods or midpoint methods.

2. Damage oriented methods, or endpoint methods.

Consider, for instance, CFCs

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Step two: classification

Once the category indicators are selected, the next step is to assign the results of the LCI to the category indicators

Next table shows the interrelationship between midpoints categories and endpoints categories for common impacts found in a food-production systems.

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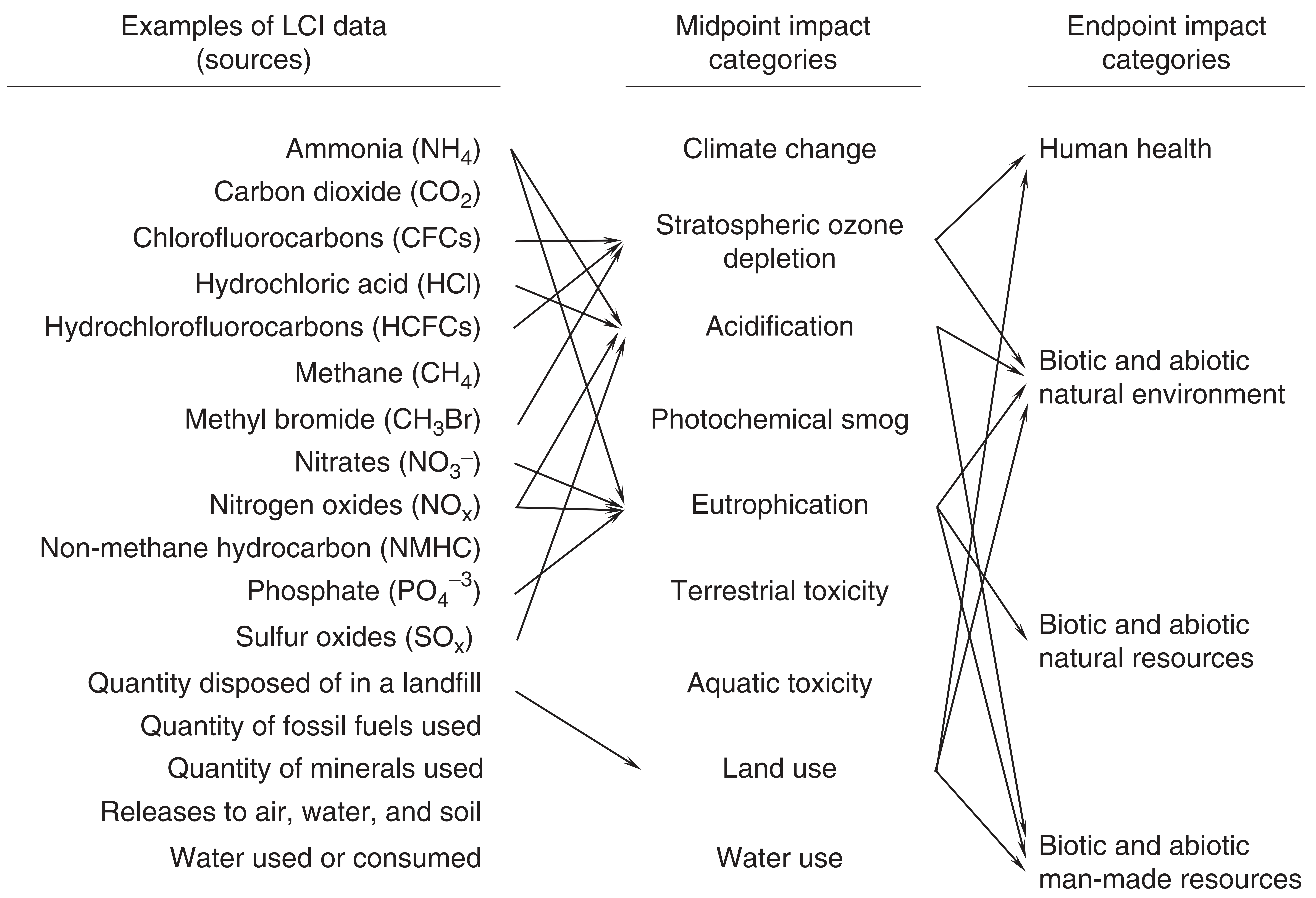

Examples of LCI data (sources)
Midpoint impact categories
Endpoint impact categories
Ammonia (NH4)
Carbon dioxide (CO2)
Chlorofluorocarbons (CFCs)
Hydrochloric acid (HCl)
Hydrochlorofluorocarbons (HCFCs)
Methane (CH4)
Methyl bromide (CH3Br)
Nitrates (NO3–)
Nitrogen oxides (NOx)
Non-methane hydrocarbon (NMHC)
Phosphate (PO4−3)
Sulfur oxides (SOx)
Quantity disposed of in a landfill
Quantity of fossil fuels used
Quantity of minerals used
Releases to air, water, and soil
Water used or consumed
Climate change
Stratospheric ozone depletion
Acidification
Photochemical smog
Eutrophication
Terrestrial toxicity
Aquatic toxicity
Land use
Water use
Human health
Biotic and abiotic natural environment
Biotic and abiotic natural resources
Biotic and abiotic man-made resources

Step three: characterization

Characterization is the assessment of the magnitude of potential impacts of each inventory flow into its corresponding environmental impact.

Impact categories can have global, regional, or local scales.

Impact characterization uses science-based conversion factors, called *characterization factors*, to convert and combine the LCI results into representative indicators of impacts on human and ecological health.

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Step three: ccharacterisation

Characterization provides a way to directly compare the LCI results within each impact category to establish relative impacts.

Impact indicators are calculated using the following equation:

$$\textit{Impact indicator} = \textit{Inventory data} \times \textit{Characterization factor}$$

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Step four: presentation after characterisation

After the characterization data generated in the previous three steps needs to be compiled and presented as:

- an LCIA profile containing category indicator results for different impact categories,
- an inventory of elementary flows that have not been assigned to impact categories, ***or***
- a set of data that does not represent elementary flows.

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Single indicators for LCA
EPS

It is desirable to have a single indicator that aggregates all the results of an LCA in one single score.

Several methods have been proposed, but still no score has been universally accepted.

Among the most well-known methods are EcoPoints, Environmental Priority Strategies (EPS), and Eco-Indicator.

EcoPoints is a measure in a single score of the overall impact of products or processes on the environment.

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EPS

EPS works on the principle that importance of an effect is evaluated in terms of the distance between the current level and the target level of the particular effect.

The EPS method is a holistic approach that calculates the total “environmental impact load” of the product during it life cycle and is expressed in environmental load units.

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Eco-Indicator

The Eco-Indicator is probably the most accepted single-score indicator method.

It is a distance-to-target method that works on the grounds that the severity of an effect depends on the current values in reference to the desired values.

Effects listed in the Eco-indicator are greenhouse effect, ozone layer depletion, human toxicity (air), human toxicity (water), human toxicity (soil), ecotoxicity (water), ecotoxicity (soil), summer smog, acidification, eutrophica- tion, odor, depletion of biotic and abiotic raw materials, noise, ecosystem degradation, and direct victims.

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