Chapter 4 : The ISO LCA Standard – Goal and Scope

We have discussed many of the skills necessary to complete an LCA. Now we present the framework for planning and organizing such a study. In this chapter, we introduce and discuss standards (specifically environmental standards), and supplement information found in the official ISO Standard for LCA. We only summarize and expand on the most critical components, thus this chapter is not intended to be a substitute for reading and studying the entire ISO Standard (likely more than once to gain sufficient understanding). The rationale for studying the ISO Standard is to build a solid foundation on which to understand the specific terminology used in the LCA community and to learn directly from the Standard what is required in an LCA, and what is optional. We use excerpts and examples from completed LCA studies to highlight key considerations since examples are generally lacking in the Standard. As such, the purpose of this chapter is not to re-define the terminology used but to help you understand what the terms mean from a practical perspective.

Learning Objectives for the Chapter

At the end of this chapter, you should be able to:

1. Describe types of standards, and the entities and processes that create them.

2. Describe the four major phases of the ISO LCA Standard

3. List all of the ISO LCA Standard study design parameters (SDPs)

4. Review SDPs given for an LCA study and assess both their appropriateness and potential challenges in using them

5. Generate specific SDPs for an LCA study of your choosing

Introduction to Standards

Before we specifically discuss the LCA Standard, we review standards in general. **Standards** are an agreed way of doing something and may be created to make a specific activity or process consistent, or to be done using common guidelines or methods. They might also be created to generally level the playing field in a particular market by ensuring that everyone produces or operates the same way, such as with the same management systems. Standards are made for a variety of reasons, and exist at many levels, from local (e.g., building codes) up to global levels. They are often backed by significant research effort. Figure 4-1 shows a summary of the kinds of standards produced.

Type of Standard	Description	Example Application
Specifications	A prescriptive set of absolute requirements	Product Safety
Codes of practice	Recommendations of practices	Construction
Methods	A prescriptive way of measuring or testing	Materials testing
Terminology or Vocabulary	A set of terms and definitions	Conformity
Product or Process	A set of qualities or requirements to ensure effective function or level of service	Medical devices

Figure 4-1: Types of Standards and Example Applications (BSI 2017)

There are many entities around the world that work on developing and promoting the use of standards. These entities may represent groups of producers, consumers, retailers, industry associations, or regulators. ASTM International has been developing standards for specific tests and materials for more than 100 years. In the civil engineering and construction sector, there are standards for concrete; for example, a project request for proposals could require that all material used meet 'ASTM C94 concrete'. This means that any concrete used in the project must meet the testing standard defined in ASTM C94, developed by ASTM. ISO (the International Organization for Standardization – the acronym is really the Greek word 'iso' meaning 'same' or 'equal') creates standards geared towards safety, quality, and management standards, and various companies and entities around the world follow these standards. Professional societies like the Institute for Electrical and Electronics Engineers (IEEE) have affiliated standards associations that create standards related to information and communication technology devices, such as the IEEE networking standards for wireless networking (802.11). National entities, such as the US National Institute for Standards and Technology (NIST) or others around the world, initiate or support work on standards of national interest, and also perform conformity assessment, which is activities to ensure adherence to standards. Without standards, different companies could make products with limited interoperability, or use materials with unknown or highly uncertain performance.

The ISO standard development process has the following components: it (1) responds to a market need; (2) is based on expert opinion; (3) is developed by a multi-stakeholder team; and (4) is ratified by consensus. The actual standard is drafted, edited, and revised by a technical committee of global experts based on comments until consensus (75% agreement) is reached (ISO 2012). Standards developed by other organizations follow a similar process flow but may vary in terms of ratification requirements, time in review, etc.

Two prominent examples of global management standards are the ISO 9000 and ISO 14000 families. The ISO 9000 family developed quality management systems for organizations to improve their consistency. The ISO 9000 standards were first formalized in 1987 via participation by industry associations, manufacturers, and national entities, and have been updated several times (most recently in 2008). This family of standards has led to significant improvements around the world in managing the production of high-value manufactured products and services by innovative processes and tracking of quality indicators. In the 1990s, entities around the world began to work on an analogous set of standards to promote high-value environmental management systems through improved management frameworks and indicators (ISO 14000), with the first version in 1996 and the most recent in 2015. ISO 14000 is more than just a management framework. Specific standards under the ISO 14000 umbrella provide standards for environmental auditing and labeling, environmental communication, and greenhouse gas reporting. These two examples of standards inspire how multiple groups come together to create a standard, and that they can evolve over time.

The Life Cycle Assessment Standard

There are various frameworks for performing life cycle assessment (LCA) but the primary and globally accepted way of doing it follows the **ISO LCA Standard** (which is comprised primarily of two related standards, 14040:2006 and 14044:2006), which we assume you have accessed and read separately. We will refer to both underlying standards as the ISO Standard. The notation "14040:2006" means that the ISO LCA Standard is in the "ISO 14000" family of standards. The version current as of the time of writing this book was most recently updated in 2006. The first version of the ISO LCA Standard was published in 1997.

One thing that you may now realize is that many of the foundational life cycle analyses mentioned in Chapter 1 (e.g., by Hocking, Lave, etc.) were completed before the LCA Standard was formalized. That does not mean they were not legitimate life cycle studies – it just means that today these could not be referred to as **ISO compliant**, i.e., that the study conforms to the LCA Standard as published. While it may seem trivial, compliance with the many ISO standards is typically a goal of an entity looking for global acceptance and recognition. This is not just in the LCA domain – firms in the automotive supply chain seek "ISO 9000 compliance" to prove they have quality programs in place at their companies that meet the standard set by ISO, so they are able to do business in that very large global market.

It should be obvious why an LCA standard is desirable. Without a formal set of requirements and/or guidelines, anyone could do an LCA according to her own views of how a study should be done and what methods would be appropriate to use. In the end, 10 different parties could each perform an LCA on the same product and generate 10 different answers. The LCA Standard helps to normalize these efforts. However, as we will see below, its rules and guidelines are not overly restrictive. Simply having 10 parties conforming to the Standard does not guarantee you would not still generate 10 different answers! One could alternatively argue that in a field like LCA, a diversity of thoughts and approaches is desirable, and thus, that having a prescriptive standard stifles development of methods or findings.

As you have read separately, the ISO LCA Standard formalizes the quantitative modeling and accounting needs to implement life cycle thinking to support decisions. ISO 14040:2006 is the current 'principles and framework' of the Standard, and is written for a managerial audience while ISO 14044:2006 gives the 'requirements and guidelines' as for a practitioner. Given that you have already read the Standard (and have their glossaries of defined terms to help guide you), you are already familiar with the basic ideas of inputs, outputs, and flows.

At a high level, Figure 4-2 summarizes the ISO LCA Standard's 4 phases: goal and scope definition, inventory analysis, impact assessment, and interpretation. The **goal and scope** are statements of intent for your study, and part of what we will refer to as the **study design parameters** (discussed below). They explicitly note the reason why you are doing the study, as well as the study reach. In the **inventory analysis** phase, you collect and document the data needed (e.g., energy use and emissions of greenhouse gases) to meet the stated goal and scope. In **the impact assessment** phase you transition from tracking simple inventory results like greenhouse gas emissions to impacts such as climate change. Finally, the **interpretation phase** looks at the results of your study, puts them into perspective, and may recommend improvements or other changes to reduce the impacts.

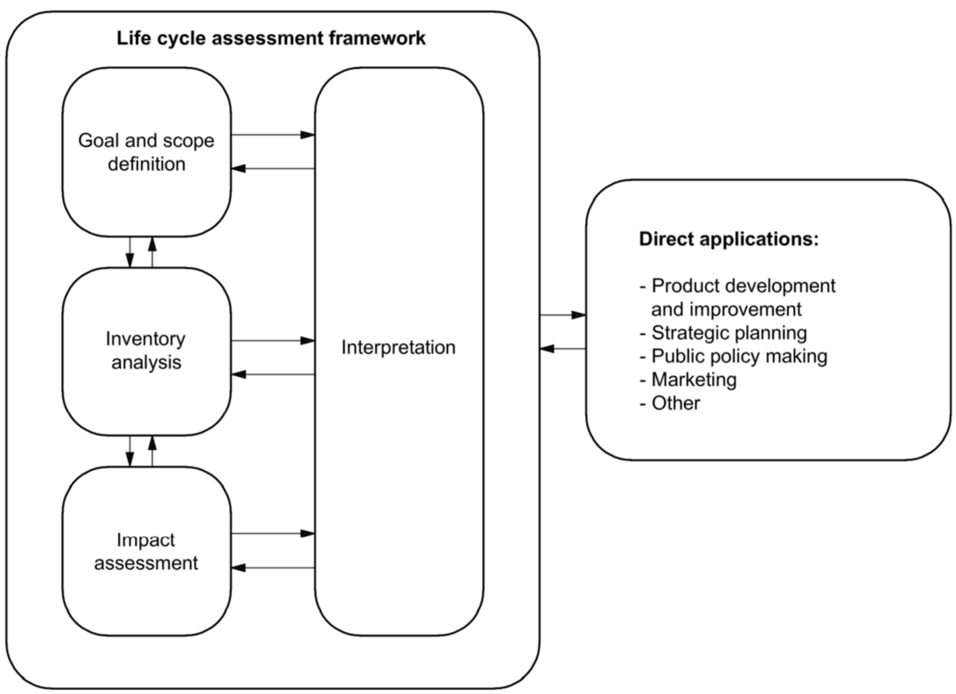

Figure 4-2: Overview of ISO LCA Framework (Source: ISO 14040:2006)

It is important to recognize that all of the double arrows mean that the four phases are iterative, i.e., you might adjust the goal and scope after trying to collect inventory data and realizing there are challenges in doing so. You may get to the interpretation phase and realize the data collected does not help answer the questions you wanted and then revise the earlier parts. You may get unexpected results that make reaching a conclusion difficult, and need to add additional impact assessments. Thus, none of the phases are truly complete until the entire study is complete. From experience, every study you do will be modified as you go through it. This is not a sign of weakness or failure; it is the prescribed way of improving the study as you learn more about the product system in question.

As ISO mentions, it is common for a study following the Standard to exclude an impact assessment phase, but such a study is called a **life cycle inventory** (LCI). That is, its final results are only the accounting-like exercise of quantifying total inputs and outputs without any consideration of impact. You could interpret this to mean that impact assessment is not a required component, but more correctly it is required of an LCA study but not an LCI. That said, we will generally use the phrase "LCA" to refer either to an LCA or an LCI, as is common in the field. Its also worth noting that LCA stands for life cycle *assessment* not life cycle *analysis*, which recognizes that an assessment is typically required for a comparative study to be useful. Finally, it may be impossible to produce an objective LCA, one where no value judgments have been made.

The right hand side of Figure 4-2 gives examples of how LCA might be used. The first two, for product improvement and strategic planning, are common. In this book we focus more on "big decisions" and refer to activities such as informing public policy (e.g., what types of incentives might make paper recycling more efficient?) and assessing marketing claims. In these domains the basis of the study might be in comparing between similar products or technologies.

In the rest of this chapter, we focus on the goal and scope phases of LCA. Subsequent chapters discuss the inventory, interpretation, and impact assessment phases in greater detail.

ISO LCA Study Design Parameters

As noted above, ISO requires a series of parameters to be qualitatively and quantitatively described for an LCA study, which in this text we refer to as the study design parameters (SDPs), listed in Figure 4-3. SDP is a phrase we created to help teach the topic, but that is not listed in the ISO Standard. We discuss some of the relevant components in this Chapter, and save discussion of others for later in the book. In this section we provide added detail and discussion about the underlying needs of each of these parameters and discuss hypothetical parameter statements and values in terms of their ISO conformance.

Goal	Scope Items: Product System System Boundary Functional Unit Inventory Inputs and Outputs LCIA Methods Used

Figure 4-3: Study Design Parameters (SDPs) of ISO LCA Framework

Think of the SDPs as a summary of the most important organizing aspects of an LCA. The SDPs are a subset of the required elements in an LCA study, but are generally the most critical considerations and thus those that at a glance would tell you nearly everything you needed to know about what the study did and did not seek to do. Thus, these are items that need to be chosen and documented very well so there is no confusion. In documenting each in your studies, you should specifically use the keywords represented in the Standard (e.g., "the goal of this study is", "the functional unit is", etc.) Expanding on what is written in the ISO LCA Standard we discuss each of the items in the SDP below.

SDP 1. Goal

The goal of an LCA must be clearly stated. ISO requires that the goal statement include unambiguous statements about four items: (1) the intended application, (2) the reasons for carrying out the study, (3) the audience, and (4) whether the results will be used in comparative assertions released publicly. An easy way to think about the goal statement of an LCA report is that it must fully answer two questions: "who might care about this and in what context?" (for points #3 and #4) and "why we did it and what will we do with it?" (#2 and #1). As noted above, the main components of an LCA are iterative. Thus, it is possible you start an LCA study with a goal, and by going through the effort needed to complete it, the goal is changed because more or less is possible than originally planned.

Below are excerpts of the goal statement from an LCA study comparing artificial and natural Christmas trees bought in the US[3] (PE Americas 2010).

> "The findings of the study are intended to be used as a basis for educated external communication and marketing aimed at the American Christmas tree consumer."

> "The goal of this LCA is to understand the environmental impacts of both the most common artificial Christmas tree and the most common natural Christmas tree, and to analyze how their environmental impacts compare."

[3] In the interest of full disclosure, one of the authors of this book (HSM) was a paid reviewer of this study.

> "This comparative study is expected to be released to the public by the ACTA to refute myths and misconceptions about the relative difference in environmental impact by real and artificial trees."

From these sentences, we can understand all 4 of the ISO-required items of the goal statement. The intended application is external marketing. The reasons are to refute misconceptions. The audience is American tree consumers. Finally, the study was noted to be planned for public release (which was a vague statement at the time - but it was released and is available on the web). We will discuss further implications of public studies later.

The examples above help constitute a good goal statement. It should be clear that skipping any of the 4 required items or trying to streamline the goal for readability could lead to an inappropriate goal statement. For example, the sentence "This study seeks to find the energy use of a power plant" is clear and simple but only addresses one of the four required elements of a goal. It also never uses the word "goal" which could be perceived as stating no goal.

Beyond the stated goals, we could consider what is not written in the goals. From the above statements, there would be no obvious use of the study by a retailer, e.g., to decide whether to stock one kind of tree over another. It is useful to consider what a reader or reviewer of the study would think when considering your goal statement. A reviewer would be sensitive to biases and conflicts, as well as creative use of assumptions in the SDP that might favor one alternative over others. Likewise, they may be sensitive to the types of conclusions that may arise from your study given your chosen goals. You want to write so as to avoid such interpretations.

One of the primary reasons that analysts seek to use LCA is to make a **comparative assertion**, which is when you compare multiple products or systems, such as two different types of packaging, to be able to conclude and state (specifically, to make a claim) that one is better than the other (has lower impacts). As noted above, the ISO LCA Standard requires that such an intention be noted in the goal statement.

Scope

Although ISO simply lists "goal and scope", a goal statement is just a few sentences while the scope may be several pages. The study scope is not a single statement but a collection of qualitative and quantitative information denoting what is included in the study, and key parameters that describe how it is done. Most of the SDPs are part of the scope. There are 12 separate elements listed in ISO's scope requirements, but our focus is on five of them that are part of the SDPs: the product system studied, the functional unit(s), system boundaries, and the inventory and/or impact assessments to be tracked. The other ten are important (and required for ISO compliance) but are covered sufficiently either in the ISO Standard or elsewhere in this book.

While these five individual scope SDPs are discussed separately below, they are highly dependent on each other and thus difficult to define separately. We acknowledge that this interdependency of terminology typically confuses most readers, as every definition of one of the scope SDPs contains another SDP term. However, a clear understanding of these terms is crucial to the development of a rigorous study and we recommend you read the following section, along with the ISO Standard, multiple times until you are comfortable with the distinctions.

SDP 2. Functional Unit

While we list only the functional unit as an SDP, the ISO Standard requires a discussion of the function of the product system as well. A **product system** (as defined in ISO 14040:2006 and expanded upon below) is a collection of processes that provide a certain function. The **function** represents the performance characteristics of the product system, or in layman's terms, "what does it do?" A power plant is a product system that has a function of generating electricity. The function of a Christmas tree product system is presumably to provide Christmas joy and celebrate a holiday. The function of a restroom hand dryer is drying hands. The function of a light bulb is providing light. In short, describing the function is pretty straightforward, but is done to clarify any possible confusions or assumptions that one might make from otherwise only discussing the product system itself.

The **functional unit**, on the other hand, must be a clearly and quantitatively defined measure relating the function to the inputs and outputs to be studied. Unfortunately, that is all the description the ISO Standard provides. This ambiguity is partly the reason why the expressed functional units of studies are often inappropriate. A functional unit should quantify the function in a way that makes it possible to relate it to the relevant inputs and outputs (imagine a ratio representation). As discussed in Chapter 1, inputs are items like energy or resource use, and outputs are items like emissions or waste produced. You thus need a functional unit that *bridges* the function and the inputs or outputs. Your functional unit should explicitly state units (as discussed in Chapter 2) and the results of your study will be normalized by your functional unit.

Building on the examples above, a functional unit for a coal-fired power plant might be "one kilowatt-hour of electricity produced". Then, an input of coal could be described as "kilograms of coal per one kilowatt-hour of electricity produced (kg coal/kWh)" and a possible output could be stated as "kilograms of carbon dioxide emitted per kilowatt-hour of electricity produced (kg CO_2/kWh)." For a Christmas tree the functional unit might be "one holiday season" because while one family may leave a tree up for a month and another family for only a week, both trees fulfill the function of providing Christmas joy for the holiday season. For a hand dryer it might be "one pair of hands dried". For a light bulb it might be "providing 100 lumens of light for one hour (a. k. a. 100 lumen-hours)". All of these are appropriate because they discuss the function quantitatively and can be linked to study results. Figure 4-4 summarizes the bridge between function, functional units, and possible LCI results for the four product systems discussed. While not explicit to function, you could have a study where your functional unit was "per widget produced" which would encompass the cradle to gate system of making a product.

Product System	Function	Functional Unit	Example LCI Results
Power Plant	Generating electricity	1 kWh of electricity generated	kg CO_2 per kWh
Christmas Tree	Providing holiday joy	1 undecorated tree over 1 holiday season	MJ energy per undecorated tree per holiday season
Hand Dryer	Drying hands	1 pair of hands dried in a restroom facility	MJ energy per pair of hands dried in restroom
Light Bulb	Providing light	100 lumens light for 1 hour (100 lumen-hrs)	g Mercury per 100 lumen-hrs

Figure 4-4: Linkages between Function, Functional Unit, and Example LCI Results for hypothetical LCA studies

The functional unit should as far as possible relate to the functions of the product rather than to the physical product. For example, "seating support for one person working at a computer for one year" is preferable to "one computer workstation chair", "freezing capacity of 200 dm^3 at -18°C" is preferable to "one 200 dm^3 refrigerator", and "annual lighting of a work area of 10 square meters with 30 lux" is preferable to "bulbs providing 30,000 lumen for one year". In this way, it is ensured that all obligatory properties - as well as the duration of the product performance - are addressed. ISO 14049:2002 (Section 3) provides additional suggestions.

Now that we have provided some explicit discussion of functional units, we discuss common problems with statements of functional units in studies. One common functional unit problem is failure to express the function quantitatively or without units. Often, suggested functional units sound more like a function description, e.g., for a power plant "the functional unit is generating electricity". This cannot be a viable functional unit because it is not quantitative and also because no unit was stated. Note that the units do not need to be SI-type units. The unit can be a unique unit relevant only for a particular product system, as in "1 pair of hands dried".

Another common problem in defining a study's functional unit is confusing it with the inputs and outputs to be studied. For example, "tons of CO_2" may be what you intend to use in your inventory analysis, but is not an appropriate functional unit because it is not measuring the function, it is measuring the greenhouse gas emission outputs of the product system. Likewise, it is not appropriate to have a functional unit of "kg CO_2 per kWh" because the CO_2 emissions, while a relevant output, have nothing to do with the expression of the function. Further, since results will be normalized to the functional unit, subsequent emissions of greenhouse gas emissions in such a study would be "kg CO_2 per kg CO_2 per kWh", which makes no sense. Thus, product system inputs and outputs do not belong in a functional unit definition.

For LCA studies that involve comparisons of product systems, choices of functional units are especially important because the functional unit of the study needs to be unique and consistent across the alternatives. For example, an LCA comparing fuels needs to compare functionally equivalent units. It would be misleading to compare a gallon of ethanol and a gallon of gasoline (i.e., a functional unit of gallon of fuel), because the energy content of the fuels is quite different (gasoline is about 115,000 BTU/gallon while ethanol (E100) is about 75,000 BTU/gallon). In terms of function or utility, you could drive much further with a gallon of gasoline than with ethanol. You could convert to gallons of gasoline equivalent (GGE) or perhaps use a functional unit based on energy content (such as BTU) of fuel, or based on driving 1 mile. Likewise, if comparing coal and natural gas to make electricity, an appropriate functional unit would be per kWh or MWh, not per MJ of fuel, which ignores the differences in the energy content of these fuels and in the efficiencies of coal-fired and NG-fired boilers.

In their detailed LCA guidance, Weidema et al. (2004) stress that for comparative studies the functional unit must be defined in terms of *the obligatory product properties required by the customers in the market on which the product is sold*. The obligatory product properties are those that the product *must have* in order to be at all considered as a relevant alternative by the customers. More details on market segmentation can be found in Weidema et al. (2004).

Using an inappropriate function or functional unit will lead to lots of wasted effort if a study were later reviewed and found to be faulty. If you were to use functional units that, for example, had no actual units, you would create results that were not normalized to anything. Having to go back and correct that after a study is done is effectively an entirely new study.

SDPs 3 and 4. Product System and System Boundary

Before discussing an ISO LCA product system, we first discuss **products**, which can be any kind of good or service. This could mean a physical object like a component part, or software or services. **Processes**, similarly are activities that transform inputs to outputs. As already mentioned, an ISO LCA product system is the definition of the relevant processes and flows related to the chosen product life cycle that lead to one or more functions. Even virtual products like software (or cloud services) have many processes needed to create them. Products are outputs of such systems, and a product flow represents the connection of a product between product systems (where it may be an output of one and an input of another). For example, the product output of a lumber mill process—wood planks—may be an input to a furniture manufacturing process. Similarly, petroleum is the product output of an oil extraction process and may be an input into a refinery process that has product outputs like gasoline and diesel fuels.

A product system is comprised of various subcomponents as defined below, but is generally comprised of various processes and flows. The **system boundary** notes which subset of the overall collection of processes and flows of the product system are part of the study, in accordance with the stated study goals.

While not required, a diagram is crucial in helping the audience appreciate the complexity of the product system and its defined system boundary. The diagram is created by the study authors (although it may be generated by the LCA software used in the study). This diagram should identify the major processes in the system and then explicitly note the system boundary chosen, ideally with a named box "system boundary" around the processes included in the study. Alternatively, some color-coded representation could be used to identify the processes and flows contained within the boundary. Even with a great product system diagram, the study should still discuss in detailed text the various processes and flows. Figure 4-5 shows the generic product system and system boundary example provided in ISO 14040:2006. If your study encompasses or compares multiple products, then you have to define several product systems.

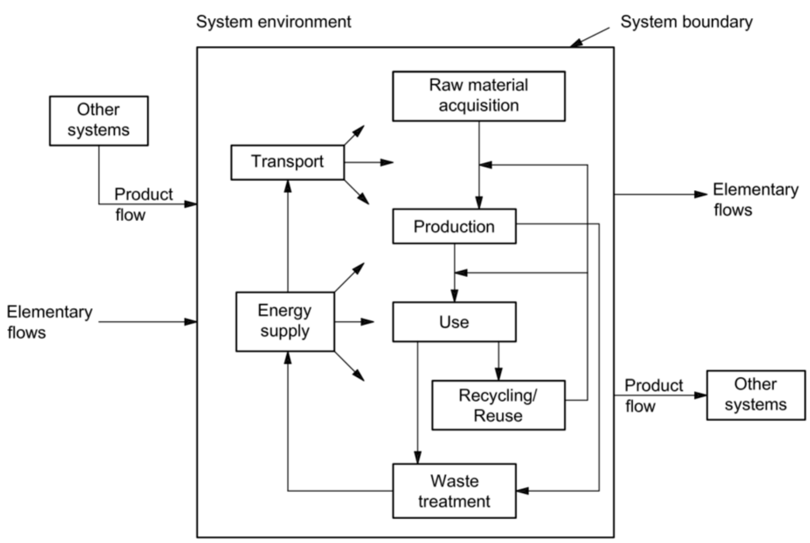

Figure 4-5: ISO 14040 Product System and System Boundary example

There are a few key components of a product system diagram (also called a **process flow diagram**). Boxes in these diagrams represent various forms of processes, and arrows represent flows, similar to what might be seen in a mass balance or materials flow analysis. Boxes (or dashed lines) may represent system boundaries. At the highest level of generality (as in Figure 4-5) the representation of a product system may be such that the process boxes depicted correspond to entire aggregated life cycle stages (raw materials, production, use, etc.) as discussed in Chapter 1. In reality each of these aggregated stages may be comprised of many more processes, as we discuss below.

It is worth discussing the art of setting a system boundary in more detail. Doing an LCA that includes data on every *specific* process in the product system of a complicated product is impossible. An automobile has roughly 30,000 components. Tens of thousands of specific processes are involved in mining the ores, making the ships, trucks, and railcars used to transport the materials, refining the materials, making the components, and assembling the vehicle. However, a reasonably aggregated LCA could be done of the product system that incorporates all relevant aspects but sacrifices some level of process-specific detail.

LCA models are able to capture direct and indirect effects of systems. In general, **direct effects** are those that happen directly as a result of activities in the process in question. **Indirect effects** are those that happen as a result of the activities, but outside of the process in question. For example, steel making requires iron ore and oxygen directly, but also electricity, environmental consulting, natural gas exploration, production, and pipelines, real estate services, and lawyers. Directly or indirectly, making cars involves the entire economy, and getting *specific* mass and energy flows for the entire economy is impossible.

Since conducting a complete LCA is impossible, what can we do? As we will see below, the ISO Standard provides for ways of simplifying our analyses so as not to require us to track every possible flow. But we still need to make key decisions (e.g., about stages to include) that can eventually lead to model simplifications. Focusing on the product itself while ignoring all other parts of the life cycle would lead to inaccurate and biased results, as shown in the example of the battery-powered car in Chapter 1.

An LCA of a generic American passenger car was undertaken by the three major automobile manufacturing companies, aka the 'big three', in the US in the mid-1990s. This study looked carefully at the processes for extracting ore and petroleum and making steel, aluminum, and plastic for use in vehicles. It also looked carefully at making the major components of a car and assembling the vehicle. Given the complexity described above, the study was forced to compromise by selecting a few steel mills and plastics plants as 'representative' of all plants. Similarly, only a few component and assembly plants were analyzed. Whether the selected facilities were really representative of all plants cannot be known. Finally, many aspects of a vehicle were not studied, such as much of the transportation of materials and fuels and 'minor' components. Nonetheless, the study was two years in duration (with more than 10 person years of effort) and is estimated to have cost millions of dollars.

Thus, system boundaries need to be justified. Beyond the visual display and description of the boundary used in the study, the author should also explain choices and factors that led to the boundary as finally chosen and used. By justifying, you allow the audience to better appreciate some of the challenges faced and tradeoffs made in the study. Other justifications for system boundary choices may include statements about a process being assumed or found to have negligible impact, or in the case of a comparative study, that identical processes existed in both product systems and thus would not affect the comparison. As mentioned above, significant effort looking for data could fail, and data for a specific process may be unavailable. Proxy data from a similar alternative process could be used instead.

Process Flows

Product systems have elementary flows into and out of them. As defined by ISO 14044, **elementary flows** are "material or energy entering the system being studied that has been drawn from the environment without previous human transformation, or material or energy leaving the system being studied that is released into the environment without subsequent human transformation." Translating, that means pure flows that need no other process to represent them on the input or output side of the model.

For the sake of discussion, assume that Figure 4-5 is the product system and boundary diagram for a mobile phone. The figure shows that the product system for the mobile phone as defined with its rectangular boundary has flows related to input products and elementary flows. The input product (on the left side of the figure) is associated with another product system and is outside of the system boundary. Likewise, on the right side of the figure, the mobile phone "product flow" is an input to another system. As an example, the left side of the figure product flow could represent that the mobile phone comes with paper instructions printed by a third party (but which are assumed to not be part of the study) and on the right side could be noting that the mobile phone as a device can be used in wireless voice and data network systems (the life cycles of such equipment also being outside the scope of the study). That's not to say that no use of phones is modeled, as Figure 4-5 has a "use phase" process box inside the boundary, but which may only refer to recharging of the device. The study author may have chosen the boundary as such because they are the phone manufacturer and can only directly control the processes and flows within the described boundary. As long as their goal and scope elements are otherwise consistent with the boundary, there are no problems. However, if, for example, the study goal or scope motivated the idea of using phones to make Internet based purchases for home delivery, then the current system boundary may need to be modified to consider impacts in those other systems, for example, by including the product system box on the right.

Figure 4-5 might be viewed as implying that the elementary flows are not part of the study since they are outside of the system boundary. This is incorrect, however, because these elementary flows while not part of the *system* are the inputs and outputs of interest that may have motivated the study, such as energy inputs or greenhouse gas emission outputs. They are represented this way because they directly enter the system from the technosphere. In short, they are in the study but outside of the system.

Product system diagrams may be hierarchical. The high level diagram (e.g., Figure 4-5) may have detailed sub-diagrams and explanations to describe how other lower-level processes interact. These hierarchies can span multiple levels of aggregation. At the lowest such level, a

unit process is the smallest element considered in the analysis for which input and output data are quantified. Figure 4-6 shows a generic interacting series of three unit processes that may be a subcomponent of a product system.

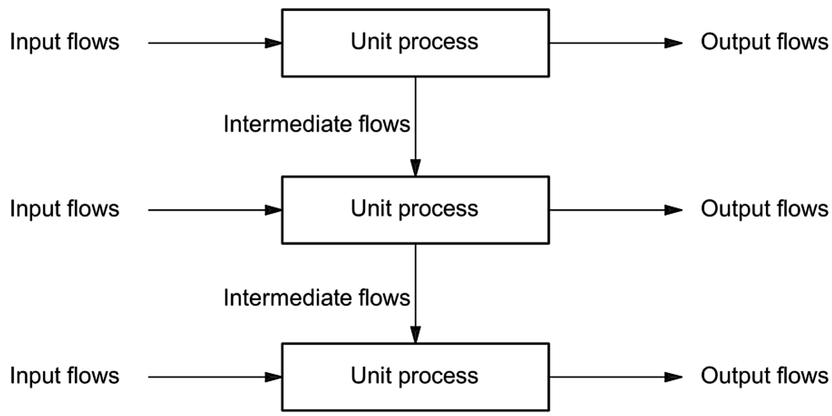

Figure 4-6: Unit Processes (Source: ISO 14040:2006)

Figure 4-7 gives an example of how one might detail the high level "Waste Treatment" process from Figure 4-5 in the manner of Figure 4-6, where the unit processes are one of the three basic steps of collecting, disassembling, and sorting of e-waste. Additional unit processes (not shown) could exist for disposition of outputs.

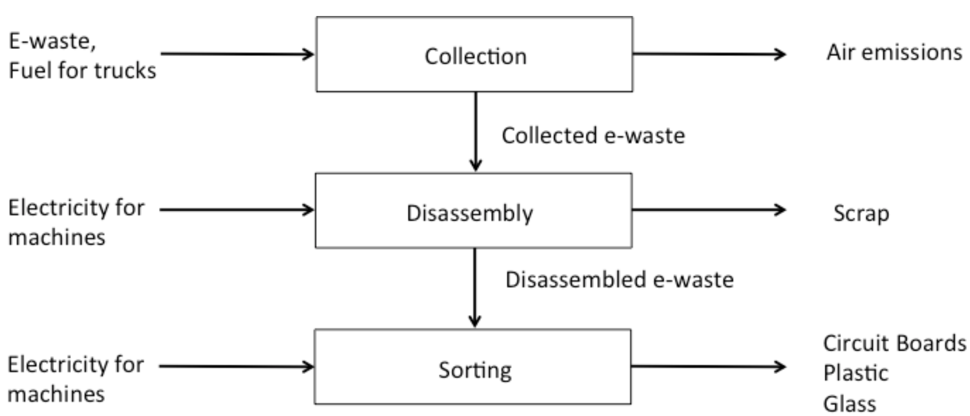

Figure 4-7: Process Diagram for E-waste treatment

It is at the unit process level, then, that inputs and outputs actually interact with the product system. While already defined in Chapter 1, ISO specifically considers them as follows. Inputs are "product, material or energy flows that enter a unit process" and may include raw materials, intermediate products and co-products. Outputs are "products, material or energy flows that leave a unit process" and may include raw materials, intermediate products, products, and releases e.g., emissions, and waste. Raw materials are "primary or secondary material that is used to produce a product" and waste is "substances or objects to be disposed of. Intermediate products flow between unit processes (such as cumulatively assembled components). Co-products are two or more products of the same process or system.

The overall inputs and outputs to be measured by the study should be elementary flows. This is why "electricity" is not typically viewed as an input, i.e., it has not been drawn from the environment without transformation. Electricity represents coal, natural gas, sunlight, or water that has been transformed by generation processes. "MJ of energy" on the other hand could represent untransformed energy inputs.

In the Christmas tree LCA mentioned above, which compares artificial and natural trees, the following text was used (in addition to a diagram): "For the artificial tree the system boundary includes: (1) cradle-to-gate material environmental impacts; (2) the production of the artificial tree with tree stand in China; (3) transportation of the tree and stand to a US retailer, and subsequently a customer's home; and (4) disposal of the tree and all packaging."

SDP 5. Inventory Inputs and Outputs

The definition of your study needs to explicitly note the inputs and/or outputs you will be focusing on in your analysis. That is because your analysis does not need to consider the universe of all potential inputs and outputs. It could consider only inputs (e.g., an energy use footprint), only outputs (e.g., a carbon emissions footprint), or both. The input and output specification part of the scope is not explicitly defined in the ISO Standard. It is presumably intended to be encompassed by the full product system diagram with labeled input and output flows. Following the example above, your mobile phone study could choose to track inputs of water, energy, or both, but needs to specify them. By explicitly noting which inputs and/or outputs you will focus on, it helps the audience better understand why you might have chosen the selected system boundary, product system, functional unit, etc. If you fail to explicitly note which quantified inputs and outputs you will consider in your study (or, for example, draw a generic product system diagram with only the words "inputs" and "outputs") then the audience is left to consider or assume for themselves which are appropriate for your system, which could be different than your intended or actual inputs and outputs. Chapter 5 discusses the inventory analysis component of LCA in more detail.

SDP 6. Impact Assessment

ISO 14040 requires you to explicitly list "the impact categories selected and methodology of impact assessment, and subsequent interpretation to be used". While we save more detailed discussion of impact assessment for Chapter 12, we offer some brief discussion and examples here so as to help motivate how and why your choice of impact assessment could affect your other SDP choices.

As we discussed in Chapter 1, there is a big difference between an inventory (accounting) of inputs and outputs and the types of impacts they can have. While we may track input and output use of energy and/or greenhouse gas emissions, the impacts of these activities across our life cycle could be resource depletion, global warming, or climate change. In impact assessment we focus on the latter issues. Doing so will require us to use other methods that have been developed in conjunction with LCA to help assess impacts. Specifically, there are impact assessment methods to consider cumulative energy demand (CED) and to assess the global warming potential (GWP) of emissions of various greenhouse gases. If we chose to consider these impacts in our study, then we explicitly state them and the underlying methods in the SDP. Again, the point of doing so explicitly is to ensure that at a glance a reader can appreciate decisions that you have made up front before having to see all of your study results.

There are other required elements for the goal and scope, as noted above, but the SDPs are the most important and time consuming. They are the scope elements that need to be most carefully worded and evaluated.

A Final Word On Comparative Assertions And Public Studies

Comparative studies can only be done if the life cycle models created for each compared product use the same study design parameters, such as the same goal and scope, functional unit, and system boundary. The ISO Standard in various places emphasizes what needs to be done if you are going to make comparative assertions. By making such assertions you are saying that applying the ISO Standard has allowed you to make the claim. For example, ISO requires that for comparative assertions, the study must be an LCA and not simply an LCI, and that a special sensitivity analysis is done. The additional rules related to when you intend to make comparative assertions are in place both to ensure high quality work and to protect the credibility of the Standard. If several high visibility studies were done without all of these special considerations, and the results were deemed to be suspicious, the Standard itself might be vulnerable to criticism.

Similarly, ISO requires an LCA to be peer reviewed if the comparative results are intended for public release. This means that a team of experts (typically three) needs to review the study, write a report of its merits, and assess whether it is compliant with the ISO Standard (i.e., whether all of the goal, scope, etc., elements have been done in accordance with what is written in the Standard). A vast majority of completed LCAs are not seen by the public, and therefore have not been peer-reviewed. That does not mean they are not ISO compliant, just that they have not been reviewed as such and designated as compliant.

E-resource: On the www.lcatextbook.com website, in the Chapter 4 folder, is a spreadsheet listing publicly available LCA studies from around the world for many different products. Amongst other aspects, this spreadsheet shows whether studies were peer reviewed (which is interesting because they have all been "released to the public" but not all have been peer reviewed). PDF files of most of the studies listed are also available. The icon to the left will be used in the remainder of the book to designate resources available on the textbook website. Readers are urged to read one or more of these public studies that are of interest to them as a means of becoming familiar with LCA studies.

Chapter Summary

The ISO LCA Standard is an internationally recognized framework for performing life cycle assessment, and has been developed and revised over time to guide practitioners towards making high-quality LCA studies. Any LCA practitioner should first read and know the requirements of the Standard. This chapter has focused on a subset of the Standard, namely the so-called study design parameters (SDPs) which comprise the main high-level variables for a study. When presented properly, SDPs allow the audience to quickly appreciate the goals and scope of the study. The chapter focused on practical examples of SDPs from actual studies and seeks to demonstrate the importance of the bridge between product systems and their functional units and LCI results. When the integrity of this bridge is maintained, and common mistakes avoided, high-quality results can be expected.

References for this Chapter

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End of Chapter Questions

Objective 1: Describe standards and the steps in creating them

1. Discuss where the LCA Standard fits within the ISO 14000 family of environmental management standards and the process used to formalize it.

Objective 2: Describe the four major phases of the ISO LCA Standard

2. Name and describe in a few sentences each of the four major phases found in the ISO LCA standard.

Objective 3: List all of the ISO LCA Standard study design parameters (SDPs)

3. Compile a list of the SDPs listed in the chapter above. For each SDP, explain in a sentence or two how it relates to the major phases and overall LCA.

Objective 4: Review SDPs given for an LCA study and assess their appropriateness and anticipate potential challenges in using them

4. Consider the following examples of goal statements for three different hypothetical LCA studies. Answer the questions (a-b) for each goal statement below.

    - "The goal of this study is to find the energy use of making ice cream."
    - "The goal of this study is to produce an LCA for internal purposes."
    - "This study seeks to do a life cycle assessment of a computer to be used for future design efforts."

    a. Briefly discuss the ISO compliance of the stated goal as written.

    b. Propose revisions if needed for the hypothetical goal statement to meet ISO requirements.

5. Read one of the LCA studies found by using the E-resource link at the end of the chapter. Summarize the study design parameters of the chosen study, and discuss any discrepancies or problems found, and how they could be improved.

Objective 5: Generate specific SDPs for an LCA study of your choosing

6. Draw a product system diagram for a paper clip labeling inputs, outputs, intermediate flows, etc., as in Figure 4-5.

7. Draw a product system diagram for the purchase of an airplane ticket via an electronic commerce website, labeling inputs, outputs, intermediate flows, etc., as in Figure 4-5.

8. For a hypothetical LCA topic of your choosing, describe how the inventory and impact sections would be compiled. Discuss the difference between impact and inventory with reference to examples from your hypothetical LCA.

9. Consider the examples of study design parameters (SDPs) for four hypothetical LCA studies in the table below.

   Fill in the rest of the entries to complete the table. Also, correct any existing entries that appear wrong. Be sure that the SDPs bridge the various elements of the study using appropriate values and units.

Product System	Function	Functional Unit	LCI Results
Printed book	Collect 100 pages of printed text		
Portable flash memory drive	Storing electronic content		energy per gigabyte
E-book reader			CO_2 emissions per reader bought
Automobile		1 mile driven	