Life Cycle Assessment in practice

- Exploring the work surrounding the Nouryon eco-footprint

Master's thesis in the programme Industrial Ecology

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SUMMARY

Life Cycle Assessment (LCA) is an emergent tool for assessing sustainability in industry by providing environmental performance data of products. While there is a large variety of standards available, as well as scientific knowledge of how to perform LCA calculations, there is little such information on how to structure the work and organization surrounding LCA, so called Life Cycle Management (LCM) or life cycle practice, i.e., how to manage data, what actors to involve, in what format to communicate the results etc. The aim of this work has been to provide insights in how LCA is practiced in industry, focusing on the company Nouryon, which has a long history of driving the sustainability agenda in the chemical industry by using LCA and what they refer to as *Eco-footprints* of products. First, the sustainability organization was mapped, in order to determine the prerequisites for practicing LCA at the company and the carrying out of eco-footprints, but also to acknowledge barriers and areas of improvements. Second, a comparison was made with external standards for environmental market communication, primarily *Environmental product declarations* (EPD) and the *Product environmental footprint* (PEF), in order to identify and evaluate aspects important to address in the Nouryon eco-footprint methodology. Lastly, suggestions on how to approach the identified barriers and areas of improvement as well as incorporating relevant aspects were presented. The outcome of this work may therefore act as a basis for further, more detailed measures for standardizing the internal work surrounding eco-footprints at Nouryon but may also provide valuable insights on life cycle practice to the LCA community as a whole.

Keywords: Life Cycle Assessment (LCA), Life Cycle Practice, Life Cycle Management (LCM), Product Environmental Footprint (PEF), Environmental Product Declaration (EPD).

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Aknowledgements

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List of Abbreviations

CEAP	Circular Economy Action Plan: EU directive involving PEF.
CEN	European Committee for Standardization
EC	European Commission
Eco-footprint	Informal environmental product decalartion used by Nouryon.
EO	Ethylene oxide - Inorganic chemical produced by Nouryon.
EPD	Environmental product declaration
EU	European Union
f.u.	Functional unit - Reference unit used in LCA
IES	Institute for environment and sustainability
ISO	International Standards Organization
JRC	Joint Research Centre – EU research institute.
KPI	Key Perfomance Indicator – Indicators for business monitoring.
KVC	Key value chain – Representative products.
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory analysis
LCIA	Life Cycle Impact Assessment
LCM	Life Cycle Management
PCR	Product Category Rule
PEF	Product Environmental Footprint
PEFCR	Product Environmental Footprint Category Rule
SIS	Swedish Institute for Standrads
SWOT-analysis	(Strengths, Weaknesses, Opportunities and Threats) assessment tool.
UN	United Nations

1 Introduction

Businesses are more and more recognizing the importance of involving sustainability and having a sustainability agenda on their own. Except for corporate social responsibility (CSR), targeting sustainability offers possibilities for growth and openings of market opportunities (Business & Sustainable Development Commission, 2017). Furthermore, with the announcement of *the European Green Deal* which involves an action plan for achieving circularity and carbon-neutrality in the EU by 2050 (European Commission [EC], 2019), it is of even higher relevance for companies on the European market to be prepared for and be able to adapt to potential new policies and directives targeting environmental performance of their products.

Life cycle assessment (LCA) has been an emergent tool for companies and organizations to be able to estimate their environmental impact of products and by that make profound decisions and to communicate environmental performance to other actors throughout shared product chains. LCA is a tool based on the methodology presented in the ISO 14040 series. The standard provides information on how to perform an LCA, including formulating a goal and scope, conduct an inventory analysis and impact assessment and to interpret the results (European Committee for Standardization [CEN], 2006). However, one can argue that equally important as to know how to perform single LCAs, is also to know how to manage the work process surrounding LCA and sustainability work in organizations: to know the specific context, where to find the relevant data, which people to involve etc. Such issues are referred to as *Life Cycle Practice* (Rex & Baumann, 2004), which in turn is a part of the concept of *Life Cycle Management* (LCM).

LCM is described as an underlying life cycle sustainability-oriented mindset; a nonexclusive framework that includes environmental, social and economic aspects of products, processes and organizations (Nilsson-Lindén, Baumann, & Rex, 2019). Traditionally LCA research has focused upon methodologies, but less on actual LCM, LCA practice and implementation of LCA in companies (Rex & Baumann, 2004). E.g., concerning environmental data, there is much information available on how to perform calculations but less on how to manage it in a transparent and efficient way (Svending, 2003) These are important in order to know how to best apply LCA but also how LCA best can support business strategies. There is therefore need of further insights in how and why companies apply LCA (Rex & Baumann, 2004).

Nouryon (formerly a part of AkzoNobel) is a global specialty chemicals manufacturer, with an estimated number of 10,000 employees located in over 80 countries. Products include a variety from intermediate chemicals used in other industry, such as ethylene and sulfur derivatives, surfactants, catalysts and specialty polymers, to end products such as ordinary table salt (Nouryon, n.d.a).

The sustainability team at Nouryon has a long history of conducting LCAs of products, that reaches back to the early 1990s (Baumann, 1998) and is now overlooking the LCA practice of the company. Identified areas of improvement are among other data management, internal and external communication, efficiency and flexibility towards customer needs and policy adaptation. The team has therefore expressed need of a documented so called *Nouryon eco-footprint methodology* that accounts for these issues and provides a way to produce and externally and internally communicate environmental data in a more efficient and transparent way.

1.1 Aim

The aim of this study was to provide insights on how LCA could be better practiced in a larger international organization, by proposing a standardized Nouryon eco-footprint methodology.

1.2 Expected outcome

The expected outcome is to increase efficiency in the work surrounding the eco-footprint. This includes to provide:

- A flow diagram describing suggested steps from receiving request for carbon or eco-data from customers to the delivery of a carbon or eco-footprint.
- Sustainability organization chart that describes which people that holds which responsibilities and competence.
- Suggestion on how to structure and manage datasets.
- Proposed way of defining goal and scopes of LCAs, and how to perform allocation, where aspects of external environmental standards have been taken into consideration.

1.3 Scope

The work has the following limitations:

- It has been carried out at Nouryon Performance Chemicals in Stenungsund but is not limited to any of the Nouryon businesses exclusively.
- The purpose of the work is to be useful for everyone working with LCA at Nouryon. Furthermore, although the results of this study may also be helpful for the overall industry, the work is foremost limited to Nouryon. Still, any such potential implications will be discussed in short.
- Even if this work includes some actual LCA of products, it is not the main purpose of the thesis work. Instead focus will be laid upon the general LCA practice.
- The work is limited in time to the spring of 2021, which will have implications in terms of assessing newer environmental assessment standards, such as e.g., *Product Environmental Footprint* (PEF) methodology, which is currently in its development phase. These will still be accounted for, however only based on the information that is available up until early spring 2021.
- The work contains two cases (EA and CMC) that have been carried out to an extent that time allowed.
- Due to the circumstances surrounding the Covid-19 pandemic work has primarily been carried out from home using digital ways of communication such as video-calls, phone and email.

1.4 Report outline

Apart from this introduction, the report includes a theoretical background, covering LCA and standards for environmental market communication in the context of Nouryon and industrial sustainability (Sections 2-5); followed by a method description, explaining how work was carried out (section 6) a presentation of the current situation in regards to the LCA organization at Nouryon (section 7); as well as an standards evaluation (section 8); and a suggested improvements for how eco-footprints may be carried out in the future (section 9). Lastly a discussion elaborating on the outcome and key take-aways and a conclusion (section 10 and 11).

2 Nouryon

Here follows a presentation of Nouryon, its sustainability agenda and use of eco-footprints.

2.1 Background

Nouryon (formerly a part of AkzoNobel) is global specialty chemicals manufacturer, with an estimated number of 10,000 employees located in over 80 different countries. The company is divided between three different *businesses*: *Performance Formulations*, *Technology Solutions* and *Nobian* (formerly *Industrial Chemicals*). Products include a variety from intermediate chemicals used in other industry, such as ethylene and sulfur derivatives, surfactants, catalysts and specialty polymers, to end products such as ordinary table salt (see table 2.1; Nouryon, n.d.a).

Table 2.1. Nouryon Businesses and examples of products, markets, end-uses and brands (Nouryon, n.d.a).

Businesses	Products	Markets	End uses	Brands
Performance Formulations	- Surfactants - Ethylene and sulphur derivatives	- Personal Care - Pharma - Food - Lubes and fuels - Mining - Agriculture - Paints and coatings - Construction - Cleaning - Textiles	- Hair gels - Skin lotions - Beds - Sofas - Refrigerators - Car seats - Pacemakers - Cement - Batteries - Asphalt - Crude oil	- Berol - Armeen - Whitebreak (Demulsifiers - Adsee - Bermocoll - Dissolvine (Chelates)
Technology Solutions	- Catalysts - Polymerization initiators - Silica - Specialty polymers - Specialty oxidants for bleaching of pulp	- Transportation - Construction - Everyday consumables	- Tissues - Diapers - Packaging - Shoe soles - Automotive parts - Solar panels - Paints and coatings - Smartphones - Wine corks - Wallpaper - Batteries - LED lamps - Pharmaceuticals	- Eka (Pulp chemicals) - Expancel (Gas filler) - Kromasil (Silica) - Levasil (Silica) - Perkadox - Thioplast (Coating) - Trigonox - Butanox
Nobian **(f. Industrial Chemicals)**	- Salt (Road & industrial salt) - Chlorine (Hydrochloric acid, iron chloride & sodium hypochlorite) - Caustics soda (lye & micro pills) - Chloromethanes (Methyl chloride, methyl chlorine, chloroform, carbon & tetrachloride)	- Textile industry - Oil and gas - Water treatment - Chlor-alkali - Chlorate industry - Food applications - Animal feed - Chemical intermediates - Disinfection/oxidation - Starch modification - Cleaning - Wastepaper - Pulp - Construction - Automotive - Cookware - Electronics	- Lightweight durable plastics - Aluminums - Pharmaceuticals - Road salt - Refrigerants	- Jozo - Suprasel - KNZ - Sanal - Broxo

Nouryon is the result of a long history of foremost Dutch, Swedish, American and German companies. The company's history traces back to 1646 and the founding of Bofors, which at that time was an iron foundry but later switched into munitions manufacturing. It became a part of Nobel Industries including several other Swedish industries and in 1994 Nobel Industries merged with the Dutch Akzo and formed AkzoNobel. In 2018 a part of AkzoNobel was acquired by the American Carlyle Group and this was to become known as Nouryon, named after Jan Nourij, one of the founders to the company Noury & Van der Lande (Nouryon, n.d.b.).

The company's strategy is:

> "to grow the leading position in specialty chemicals and exceed customer's expectations by delivering innovative and sustainable solutions that answer society's needs – today and in the future."
>
> - (Nouryon, n.d.c.)

This connects to three values: *Aim high, Own it* and *Do it right,* which is achieved by close development and collaboration together with customers and colleagues and that the company is accountable and deliver on its commitments. The company is also acting as a support for employees and the communities where it is active, in order to ensure strong ethics, safety and sustainability (Nouryon, n.d.c.)

2.2 Sustainability agenda

In terms of addressing sustainability issues, the company is committed to continuously reduce its environmental impact. It recognises the use of renewable energy and increasing energy efficiency as a way of avoiding risks connected to supply chains, improve environmental footprint and help customers with their environmental targets. It also sees that it opens new business opportunities such as e.g., green hydrogen or circular chemistry. Every quarter all manufacturing sites, offices and research facilities report on special environmental *key performance indicators* (KPIs), using a company reporting system called *Enablon*. Two times a year the sustainability steering team is assessing these KPIs, and the results are chosen to be displayed in varying ways. One of such ways is the organizational and product carbon footprint. In 2019 the scope 1-3 (cradle-to-gate) company footprint was just below 4.9 ktons of CO2. From which 40% originated from the extraction of raw materials (scope 3), 27% from energy use (scope 2) and 3% from own activities (scope 1). The average carbon footprint of products was 199 kg CO2 per ton product. A 29% decrease compared to 2009 (See figure 2.1; Nouryon, 2019).

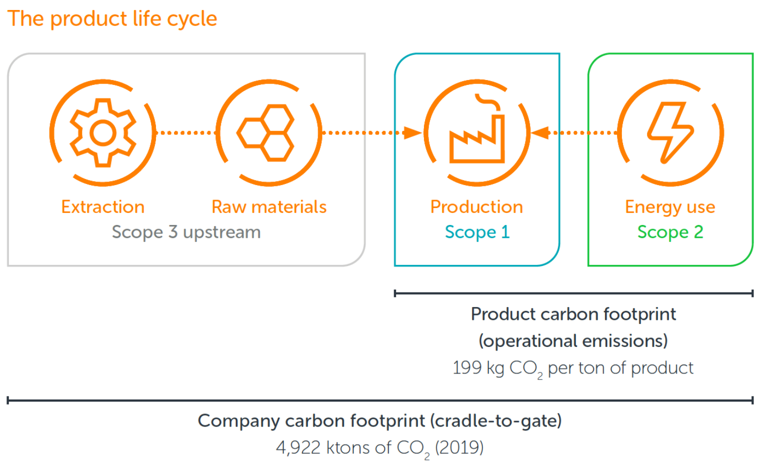

Figure 2.1. Scope of company and products carbon footprint (Nouryon, 2019).

The company is also using an operational eco-efficiency program, which aims to increase raw material efficiency while reduce energy consumption, decrease emissions to air and water and the production of waste. Measures that also reduce the overall operational costs. Figure 2.2 illustrates the development of the eco-efficiency parameters between 2009 and 2019.

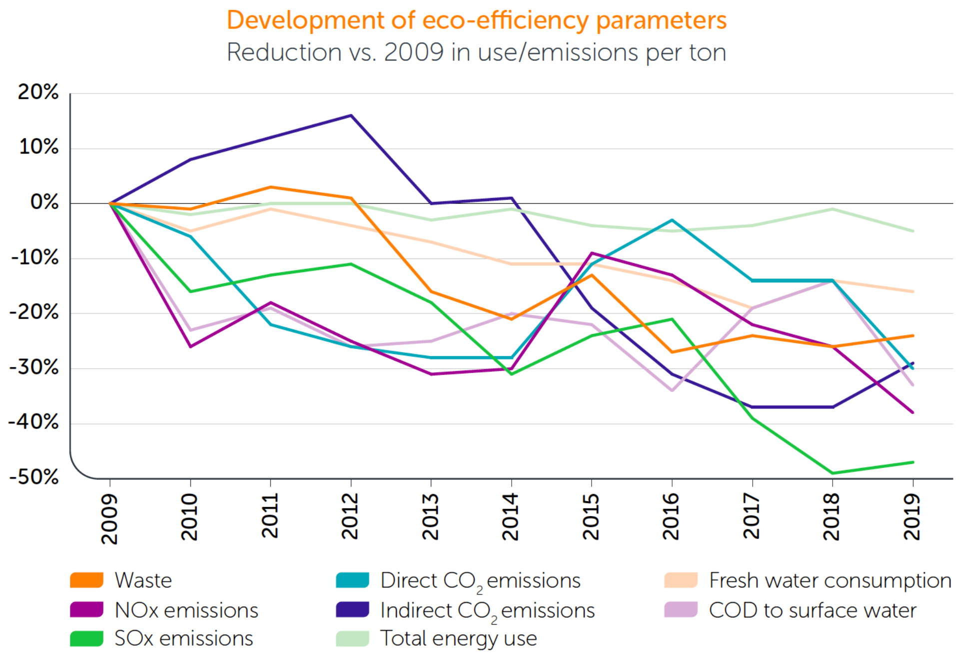

Figure 2.2. Development of eco-efficiency parameters between 2009 and 2019 (Nouryon, 2019)

Another strategy is to acknowledge products that are considerably more sustainable than most alternative products on the market. These are called *eco-premium solutions*. Criteria included are toxicity, use of energy and natural resources and materials, emissions and waste, land use, risks, health and well-being. The products are also secured from having any adverse effects in these criteria. 37 percent of the 2019 revenue was generated from sales of eco-premium solutions (Nouryon, 2019).

2.3 Eco-footprint

The so-called eco-footprint is an informal way of communicating environmental performance of products externally to customers and others interested in LCI and LCIA results of products. It can be seen as a type of declaration, sometimes in the form of a full document including environmental loads, emissions, generated waste etc, but sometimes only as an email containing a single figure or very limited information. Since the interest and demand of environmental data is increasing in general, it is necessary to overlook the work surrounding eco-footprints make it clearer and straight forward.

3 Managing industrial sustainability

Sustainability has many definitions but perhaps the most famous one was formulated in *the 1987 Brundtland Commission*, where:

> "sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs"
>
> - (World Commission on Environment and Development, 1987).

The concept of sustainable development is thereby partly about fairness, between generations but it also has a strict anthropocentric view, since the foundation is human needs. In turn, this includes three pillars, one ecological, one social and one economic. The ecological pillar refers to managing natural resources so that they can provide for us and be sustained over time; the social includes health, human rights, access to food and the economic involves managing and householding man-made and natural capital. We may not know if future generations will have different needs, but if we would at least have preserved the preconditions that we have today we can say that we have reached at least some level of sustainability (Hedenus et al, 2018).

3.1 Sustainability and business

For European business and industry there are two major policy frameworks that are addressing sustainable development. First the *Agenda 2030*, which was agreed upon by the Heads of State and Government and High Representatives in September 2015, just two months before the closing of the Paris Agreement. This framework consists of 17 *sustainable development goals* (SDGs) and 169 targets (UN, 2013). The SDGs are primarily targeting the intergovernmental and policy level, but they make an indirect important offer for companies to explore new markets, innovations and possibilities for growth (Business & Sustainable Development Commission (2017). Second, in 2019 the European commission communicated its action plan for the so called *European Green Deal*. The plan aims to make the European economy sustainable by using resources in a more efficient way, transforming into a clean circular economy, restoring biodiversity and cutting pollution. This is done by green investments, supporting innovation in industry, transportation, decarbonization in the energy sector, more energy efficient buildings and improvement of environmental standards that align with EU environmental and climate goals. The Green Deal further suggests that all chemicals, materials and products placed on the European market should align with EU regulation and these environmental standards (EC, 2019).

3.2 Sustainability and the chemical industry

The chemical industry is worth over €3000 billion. Europe holds for over €600 billion and employs 1.3 million people directly within the industry and 4 million indirectly through the supply chain and service sector. It has been a key player in the transformation into what we today regard as modern living. Just some short examples are transportation, where there are fuels, additives, catalytic converters and plastics. In clothing we use synthetic fibers, dyes and surface proofing. For safety we can have light weight polycarbonate helmets, fire retardants and air bags. In food, we use preservatives, packaging, refrigerants. For health we have chlorine for clean water, disinfectants, vaccines. In our homes we find plastics, mobile phones, detergents and in agriculture we use fertilizers and pesticides (Lancaster, 2016).

Although many of these products have contributed to a higher quality of life and increased human well-being, many are controversial and chemical industry is often viewed in bad light in terms of sustainability. History tells of several accidents and scandals involving industrial plants but also products. It is fair to agree that these companies never set out to causing harm, but the risks were there due to pressures of meeting production targets, reduce costs and foremost a lack of knowledge (Lancaster, 2016). Furthermore, when looking at GHG emissions the chemical industry is also one of the largest industrial emitters, primarily due to emissions that arise from energy production but also venting of by-products in processes (Fischedick et al., 2014).

In order to minimize the environmental impacts of the chemical industry a set of *green chemistry principles h*as been developed (see table 3.1). They provide guidance in a variety of issues such as design of chemicals, processes and facilities (Lancaster, 2016). The green chemistry principles are specific and applicable in short-term decision making. However, one can argue that what they benefit in the short-term they lack in the long-term strategic thinking of sustainability. Furthermore, since they are so many, this can lead to that they can come in conflict with each other. E.g., if use of renewable feedstocks leads to less energy efficiency and more waste.

Table 3.1. Green chemistry principles (Lancaster, 2016).

1. Prevention	Prevent emissions and waste instead of cleaning it up afterwards.
2. Atom economy	The incorporation of raw material (reactants) used in processes should be maximized in the final product.
3. Less hazardous chemical synthesis	Processes should both use and produce substances with little or no toxic properties.
4. Designing safer chemicals	Chemicals should be designed in way so that functionality is maximized while toxicity is minimized.
5. Safer solvents and auxiliaries	The use of e.g., solvents and separation agents should be minimized.
6. Design for energy efficiency	Energy requirements for processes should be recognized and minimized.
7. Use of renewable feedstocks	Raw materials should be renewable when possible.
8. Reduce derivatives	Additional reaction steps often require additional reagents and generated waste and should therefore be minimized.
9. Catalysis	Using selective catalysts decrease the energy needed for reactions to occur and speed up reaction rates.
10. Design for degradation	Chemical should be designed in a way so that they do not easily persist if released into the environment.
11. Real-time analysis for pollution prevention	Analytical methodologies that allow for real-time monitoring should be used for better control of processes.
12. Inherently safer chemistry for accident prevention	Substances used in processes should be chosen in a way that the risk of accidents (releases, explosions and fires) are minimized.

3.3 Sustainability tools

The field of addressing sustainability in business and industry includes several different concepts, tools and procedures. Concepts involve *Industrial ecology, eco-efficiency, life cycle thinking*, and *life cycle management* among others.

Industrial ecology

- takes its approach in that industrial systems can be seen as ecosystems, with similar kinds of material, energy and information flows that occur also in nature. Industrial ecology also recognizes that industrial systems are not dissociated from natural systems but are instead integrated. Industrial ecology is not only looking at materials and energy flows within industrial systems (i.e., *industrial metabolism*), but instead also on how the systems works, how it is managed and how it is interacting with the natural system. It aims to determine how industrial systems can be designed to best fit the natural system and, in that way, also contribute with ways of achieving economically feasible sustainability (Erkman, 1997).

Eco efficiency

- is one key strategic theme for business to address sustainable development. It is a measure of how well goods and services satisfy human needs while also reducing ecological impacts and resource intensity throughout the entire life cycle. I.e., it compares the economic and environmental performance of products. However, it does not include the social pillar of sustainability (Ehrenfeld, 2005)

Life Cycle Thinking

- which is more and more regarded as one of the most obvious basic logics when assessing environmental impacts, is to consider environmental impacts throughout the entire life cycle of a product (cradle-to-grave), not just in its separate phases. It is a way to avoid sub-optimizations and reduce cumulative environmental impacts throughout the value chain (Rex & Baumann, 2004).

Life cycle management (LCM)

- is one type of environmental management that involves the managerial and organizational practices of applying life cycle thinking in business. It is a relatively new field that includes LCA but also any management activities that aims to reduce environmental impacts from products (Rex & Baumann, 2004). LCM includes LCA but also other tools, e.g., design for environment (DfE) life cycle costing (LCC) and organizational LCA (O-L). Companies that want to extend their environmental management to LCM can pick freely from all these tools to design their own customized LCM that fits into their organizational context (Nilsson-Lindén, Baumann, & Rex, 2019).

Figure 3.1 provides an overview of the interrelations of these concepts together with other tools and elements related to environmental sustainability. Data is processed using different tools that are either analytical or procedural and that are concerning either environmental or social and economic aspects. Examples of analytical tools are LCA, LCC, environmental risk analysis etc. Examples of procedural tools are instead different environmental management systems, product declaration methodologies and standards. These tools, in turn utilize several technical elements such as e.g. allocation models, normalizations models, sensitivity analysis, multi-criteria analysis, fate models etc. The results are brought into decision-making and can eventually lead to implementations (Helias, al., 2008).

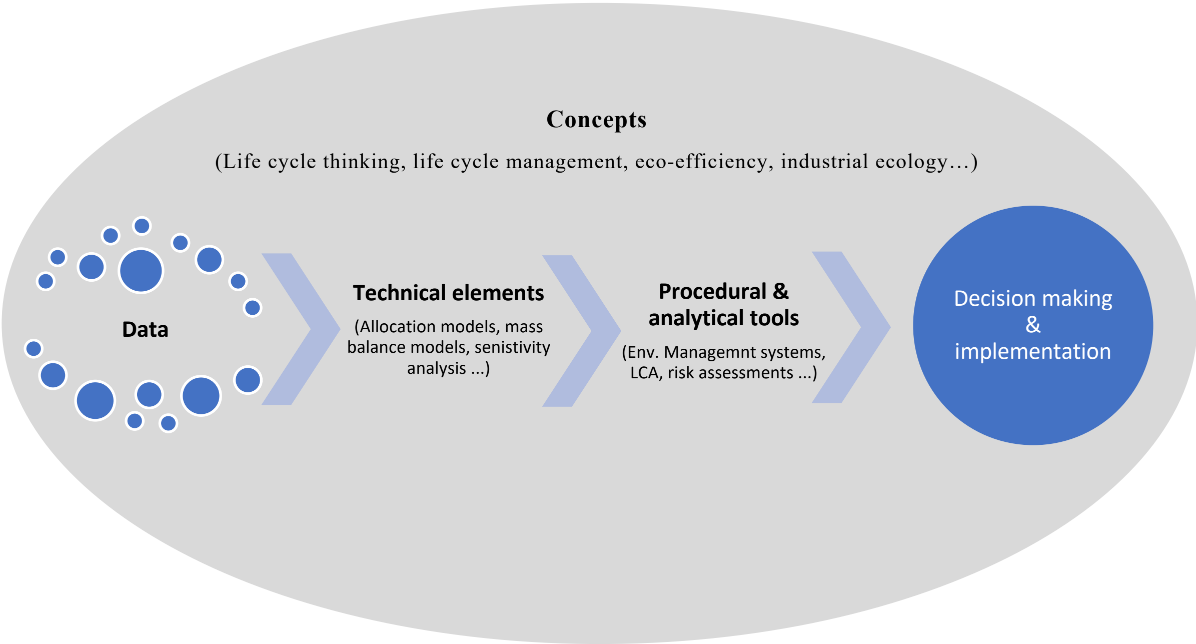

Figure 3.1. An overview of the interrelations of concepts, tools and elements related to environmental sustainability (Helias, al., 2008).

There is still little knowledge on how sustainability concepts and tools are used in business and industry. Studies have looked closer on details in everyday activities, shared routines and behavior, and concluded that although it is easy to analyze the organizational structure of a company it is also important to see where information and knowledge are exchanged (Nilsson-Lindén, Baumann, & Rex, 2019). As aforementioned, there is the example of data management that if it is carried out with care and thorough documentation, risks of misinterpretation and overlapping work can be minimized, while the chances to use the data for other applications may increase (Svending, 2003).

4 Life cycle assessment

Life cycle assessment (LCA) is the concept where a product is followed from the cradle, i.e., raw material acquisition, through industrial processes, transport, manufacture, use and finally disposal and waste management, i.e., the grave. All along the life cycle resource and energy use are quantified together with emissions arising from the life cycle. However, the concept of LCA is not exclusive to the LCA method but it also includes a more overarching methodological procedure (see figure 4.1). First the goal and scope of the study is formulated, followed by an inventory analysis of data and finally an impact assessment that includes classification and characterization and sometimes also weighting. The procedure is not as linear as it would first seem, since simultaneous interpretation and revalidation of generated results and learnings are needed (Bauman & Tillman, 2004).

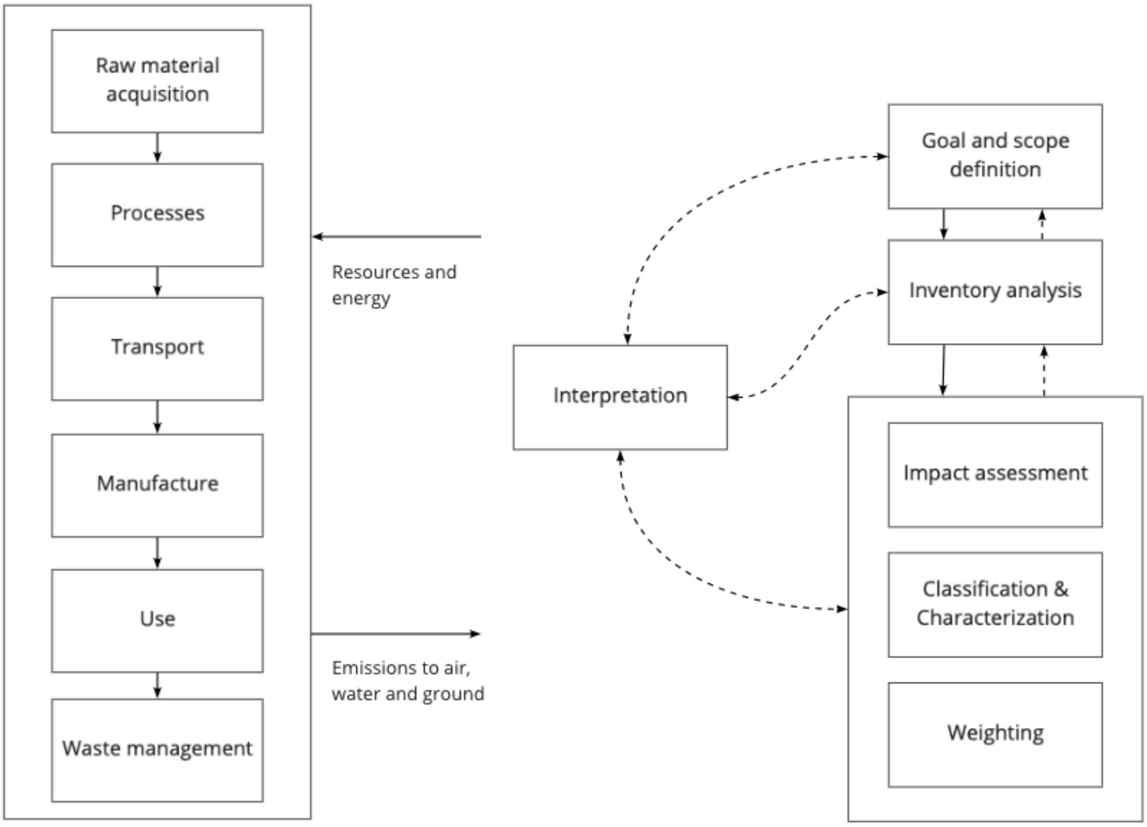

Figure 4.1 The lCA method (left) and the LCA procedure (right; Baumann & Tillman, 2004).

4.1 Goal and scope definition

LCA can be applied in many ways and for many different reasons and this is determined by the way the goal and scope are defined. The process normally involves two parties. On the one hand, the *LCA commissioner*, who has ordered the conduction of the LCA and who also has an idea of its purpose. On the other hand, the practitioner, the LCA analyst who can propose methodological choices and what implication they may have. Together they formulate a realistic goal and scope that satisfies the commissioner's needs while not exceeding any time or budget constraints (Baumann & Tillman, 2004).

In general, the goal shall include three things: *the intended application*, *the reason for carrying out the study* and *the intended audience*, I.e., why and for whom it is done. Reasons can be for marketing purposes or decision making, and audiences can be product developers, top management, customers or authorities. It is not uncommon that the goal is formulated as to answer a specific research question, e.g., regarding determining the environmental impact of a certain product, or comparing two different products to see which one is more environmentally preferable etc. (Baumann & Tillman, 2004).

The scope in turn formulates how the LCA will be carried out and it includes several considerations regarding how the system will be approached:

Modelled object

- A definition of the specific products, product design or process that are to be analyzed (Baumann & Tillman, 2004).

Initial flowchart

- A visual draft description of the system of study, including processes and flows. The reference flow, which all specific flows can be related to should be indicated (Baumann & Tillman, 2004).

Functional unit

- A visual draft description of the system of study, including processes and flows. The reference flow, which all specific flows can be related to should be indicated (Baumann & Tillman, 2004).

LCIA method

- ISO14040 only suggests resource use, ecological effects and human health as general impact categories and provides no further guidance on how to address these impacts in more detail. Hence, there are several different impact assessment methods to choose from and there is also the choice of which impact categories to include (Baumann & Tillman, 2004).

Type of LCA

- This is determined by the defined goal of the study and will in turn affect the choice of system boundary, allocation procedure, data, and system subdivision. An LCA can either be an *accounting LCA* (also called *attributional LCA*), which will determine the total environmental performance of a product or a c*hange oriented LCA* (*consequential LCA*) which instead is limited to the marginal difference between e.g., two products or an old and a new version of a product (Baumann & Tillman, 2004). Furthermore, an LCA can also be *retrospective* or *prospective,* depending on if the analyzed system is a past, current system or a future system. In a retrospective LCA, current or past data is used while in prospective mostly modelled or estimated data is used (Arvidsson et al., 2018).

Natural boundaries

- An identification of the boundaries between the analyzed technical system and the natural system, I.e., where does the life cycle begin and where does it end. Things to consider are e.g., renewable energy, landfills, resource extraction, agriculture etc. (Baumann & Tillman, 2004).

Geographical boundaries

- Parts of the life cycle will have different environmental impacts since, resource extraction, processes, infrastructure, use and waste treatment vary between different regions. Data used should preferably reflect the conditions where the life cycle is present (Baumann & Tillman, 2004).

Time horizon

- Here it is decided for how long time the production, use and waste treatment are to be studied and how long the results of the LCA are valid (Baumann & Tillman, 2004).

Cut-off criteria

- Environmental impact from e.g., production and maintenance of capital goods or personnel and are rarely included in LCA studies. The reasons are time and resource constraints in collecting and managing data and that these inputs are assumed to have low relevance and negligible environmental impact. Still, it is a subject that is widely discussed and a motivation why different choices are made may be stated. Furthermore, there is also the choice of different life cycle limitations, e.g., cradle-to-gate, or gate-to-gate, where parts of the life cycle is excluded. This choice may also be motivated (Baumann & Tillman, 2004).

Allocation

- Different life cycles often share processes. An *allocation problem* occurs when parts of the environmental impact of a shared process shall be assigned to each one of the specific life cycles. Three typical situations are: (1) *multi-output,* where several products are generated from the same process, e.g., in a chemical reactor; (2) *multi-input,* where a process has an input of several different products, e.g., in waste treatment; and (3) *Open loop recycling*, where a product is recycled into another product or when energy is recovered e.g., from waste incineration (Baumann & Tillman, 2004).

  For multi-input and multi-output, allocation problems can sometimes be avoided by increasing the level of detail, but this requires additional demand of data and work. *Partitioning* and *system expansion* are two other alternatives, where either the upstream resource consumption and emissions are divided between the different products or where the system is credited with avoided emissions elsewhere. E.g., if surplus heat is used in district heating it compensates for emissions generated if otherwise other fuels would be used. It is argued that partitioning is more useful for accounting LCA while system expansion is more applicable for change oriented LCA. ISO 14040 does not however recognize such dependence but recommends an order of preference of allocation method where: first, allocation is avoided by increased detail or systems expansion; second, partitioning is used based on physical properties such as mass or energy content; and third, partitioning is based on non-physical properties such as economic value (Baumann & Tillman, 2004).

System subdivision

- A system can be divided between a foreground and a background system. This is especially useful for change oriented LCA, where only some parts of the system are relevant. The foreground system should also reflect what processes and flows that can be directly influenced by the actor that has ordered the LCA and the background, i.e., what can be only indirectly influenced (Baumann & Tillman, 2004).

Data quality requirements

- In accordance with ISO 14041 there are eight different aspects that can be considered in terms of data quality: time, geography and technology coverage, completeness, representativeness, consistency, precision and reproducibility. These will determine the relevance, reliability and accessibility of the data (Baumann & Tillman, 2004).

Assumptions and limitations

- Here major assumptions should be included such as e.g., what the competing technologies are if doing system expansions. In addition to the limitations of the drawn system boundaries e.g., later discovering of missing datasets or similar can be mentioned (Baumann & Tillman, 2004).

4.2 Life cycle inventory assessment (LCI)

In the LCI, a flow model describing the life cycle of interest is constructed. This includes (1) a flowchart, based on the system boundaries drawn in the goal and scope definition; (2) data collection and documentation for all the processes and flows within the system; and (3) recalculation of data so that it is expressed regarding to the reference flow, i.e., in relation to the functional unit (Baumann & Tillman, 2004).

4.2.1 Flowchart

The flowchart is built by starting with the initial flowchart from the goal and scope definition and successively add new processes and flows along with increased learning of the system together with the data collection. This is a cumulative and iterative process where new findings and new discovered limitations and opportunities that may also inflict changes to the goal and scope definition (Baumann & Tillman, 2004).

4.2.2 Data collection

Data collection is the most time-consuming part of an LCA. *Numerical, descriptive and qualitative data* shall be found for each flow and process, i.e., all the inputs and outputs of each process in terms of amounts and types of energy, raw materials, emissions to air and water, process chemicals, waste, product of interest and other products (see figure 4.2), but also age and origin of data, process technology, and process location. If needed data supporting allocation can be relative prices of products or relations between physical properties. If there are transports, included distances, types of transportation, emission data and fuel consumption, are typical data to include (Baumann & Tillman, 2004). Further recommended data criteria can also be found in the ISO14048, which is a technical specification for the documentation of LCI data (SIS, 2002).

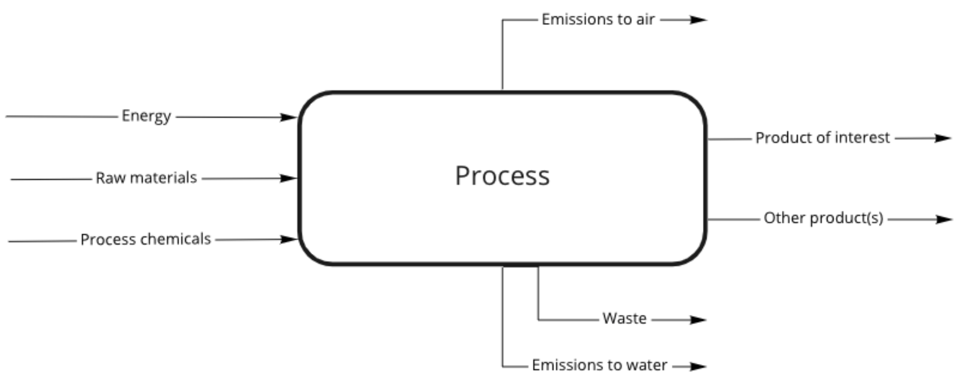

Figure 4.2. Examples of input- and output flows covered in an LCI (Baumann & Tillman, 2004).

Data collection normally means involving other actors, since it is unlikely that the practitioner him- or herself possess all necessary expertise to understand all processes and flows, but also have access to them. The first step, when collecting LCI data at a company, is normally to come in contact with suppliers of raw materials and request environmental data for these. Sometimes the supplier can provide full LCI results, but it is more likely that only data for single processes operated by the suppliers are available. More upstream data will therefore be collected either from that company or by companies further upstream. When performing cradle-to-grave LCAs the practitioner also needs to involve downstream actors such as other companies further down the product chain, consumers, and waste treatment actors. Other sources of LCI results are branch organisations that hold normally cradle-to-gate average datasets or public LCA reports. Since companies often perform LCAs internally these reports are however uncommon (Baumann & Tillman, 2004).

Important things to consider when collecting data are (Baumann & Tillman, 2004).:

- Which processes that need site-specific data and for which where average data is sufficient.
- Reading in on details and process technologies before getting in touch with other actors, in order to know what to ask for.
- What the best ways are for connecting with actors. Perhaps there are already established communication channels set up by other people in the company.
- Having a strategy for handling confidential data and information.
- If giving the data suppliers opportunity to review the use of their data in the LCI.
- To use a standardized data documentation sheet.

According to ISO 14040 data should also be verified with a validity check (CEN, 2006a), that includes e.g., a comparison of the results with other sources for similar product. It is also important to check if the data fits into the goal and scope definition.

4.2.3 Recalculation and allocation

The final calculation is done in three overarching steps. First, data for each individual process is normalized to one input or output that is part of the reference flow. Second, the flows linking the processes are calculated based on mass balance equations derived from the flowchart. Third, the flows passing the system boundary are re-calculated in relation to the reference flow. All values are now expressed *as per functional unit.* Thereafter, the results are prepared for the Life cycle impact assessment (LCIA). In terms of allocation the ISO 14044 provides some guidelines. First, it provides a stepwise procedure (CEN, 2006b):

1. If possible, allocation should be avoided by either (a) increasing the level of detail, or (b) system expansion.
2. If it cannot be avoided, allocation should be based on physical properties, such as e.g., mass or energy content.
3. Where physical conditions alone cannot be used as a basis for allocation, other relationships may be used, such as e.g., economic value.

Second, there is *the 100% rule,* which means that the sum of all allocated environmental loads shall equal the unallocated loads (Baumann & Tillman, 2004; CEN, 2006b). Lastly, when there are several allocation methods available one shall perform a sensitivity analysis (CEN, 2006b). It may not always seem straight forward, in terms of physical relationships, to use either mass, volume or mole content in relation to environmental load. Hence there is also the need to have a motivated technical-causal relationship. E.g., cadmium emissions from waste treatment can only be allocated to cadmium containing products. In terms of transportation allocation shall be based on either mass or volume dependent on which factor the transport is limited by. Furthermore, physical relationships are not always linear, and it is difficult to take this into consideration without coming in conflict with the 100% rule (Baumann & Tillman, 2004).

Except for these guidelines the ISO 14040 standard provides little information on how to make the choice of allocation method and what actual allocation methods there are to choose from. Research has therefore been put into developing such methods for a variety of different circumstances. In the case of recycling of products e.g., in particular open-loop recycling (i.e., when recycled materials are used for other products than the original, in contrast to closed-loop recycling where recycled materials are used for the same product again), there are a number of different methods available (see Appendix I: Methods for recycling for more information). The choice is depending on the formulated goal and scope definition, especially the time and resource constraint, data accessibility and knowledge and expertise of the LCA practitioner about the full life cycle including its processes. Since the choice of allocation method will have a major impact on the latter impact assessment and what processes and products that are shown to be contributing to the largest environmental load, preferably one should document and motivate the choice of allocation method in detail and possibly include a sensitivity analysis (Baumann & Tillman, 2004).

4.2.4 Energy

Energy use in itself does not have an environmental impact, but it is still included in LCI. This is because it is a measure that is relatively easy to collect and since it can be linked to emissions arising from energy generation. Often it is also easier to estimate emissions based on energy use rather than measuring emissions directly. Accounting for both mass and energy content in flows may be done with care since there is a risk of double-counting if weighting factors utilize both mass and energy of the same flows. Double-counting is also imminent if both the energy flows passing the system boundary and the internal flows are accounted for e.g., if electricity use together with primary energy (I.e., energy use for electricity production) are reported (Baumann & Tillman, 2004).

There is also the case of feedstock energy (i.e., the inherent energy content of materials). One can account for the energy content of the materials passing the system boundary. To avoid double counting one must thereby avoid include energy content from later internal material flows. This method does however not recognise any difference between the energy used within the life cycle and any remaining energy content of products in terms of heat that can potentially later be recovered. An alternative way to proceed is instead to use the heat content of products and materials to account for feed stock energy. Process energy that comes from raw materials must thereby be accounted for and now energy that is used during the life cycle is distinguished from the remaining heat content of materials and products. Lastly, waste treatment processes can generate energy reused in the process. This energy is generated from the feedstock energy of the materials entering the waste treatment. If accounted for, the feedstock energy can be credited in the life cycle by system expansion (Baumann & Tillman, 2004).

4.3 Life cycle impact assessment (LCIA)

This part of LCA translates the environmental loads from the LCI into *impacts* (or *consequences*). This is necessary in order to be able to grasp and interpreted the results in the end, and to communicate the results in an apprehensive way.

4.3.1 The steps of the LCIA

The different steps of the LCIA are displayed in figure 4.3 (CEN, 2006a). *Mandatory elements* are supposed to be strictly analytical and objective, and consist of first, an *impact category* *definition,* where the impacts relevant for the study are identified and selected. In general, there are three different overarching types of impact categories: *resource use, human health* and *ecological consequence.* This step is already taking place in the goal and scope definition but may be refined throughout the LCI process as it becomes more obvious what data that is accessible. Second, a *classification* where the parameters from the LCI are assigned to the relevant chosen impact categories; and lastly a *characterization,* where the potential environmental impact is calculated for each parameter in relation to their assigned impact categories, using *characterization factors* (also called *equivalency factors;* CEN, 2006b; Baumann & Tillman, 2004).

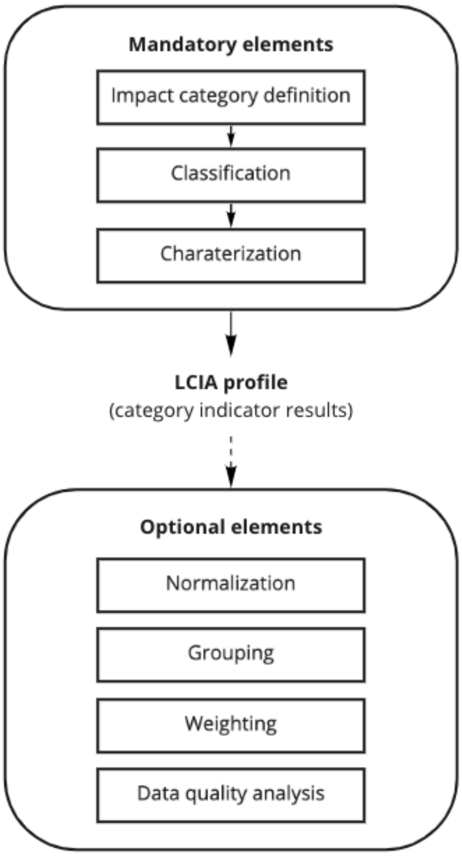

Figure 4.3. The mandatory and optional elements of the LCIA (CEN, 2006a).

In addition to the mandatory elements of the LCIA there are other *optional elements* to include depending on the goal and scope, and these also include a higher degree of subjectivity in general: *Normalization* is where the LCIA results are expressed relatively to a reference value, e.g., a geographical region, in order to better understand the extent of impact. *Grouping is* where impacts are ranked or sorted. *Weighting*, where the LCIA results are aggregated, either by e.g., monetarization, specific targets, using expert panels or technical abatement possibilities, and *Data quality analysis*. Three examples of data quality analysis tools are *Dominance analysis*, which identifies the most polluting activities in the life cycle; *Sensitivity analysis*, which identifies the LCI/LCIA data that, if changed, has the biggest impact on the LCIA results; and *Uncertainty analysis*, which identifies the uncertainty of the results by recognizing estimations, intervals and probabilities in the LCI data (Baumann & Tillman, 2004).

4.3.1.1 Choice of impact categories

The ISO 14044 further describes the requirements of the impact category definition. In general, things to consider when choosing impact categories are (CEN, 2006b):

Completeness

- the chosen impact categories should altogether grasp all major environmental aspects as well as the ones more specific for the goal and scope of the study.

Practicality

- There should not be too many chosen impact categories.

Independence

- Categories should be independent in order to avoid double counting.

Characterizable:

- There must be characterization factors so that the LCI results can be linked to the impact categories.

Environmental relevance

- Characterization factors shall be relevant to the impact category and endpoint categories.

Scientific method

- Characterization factors should be scientifically validated.

Inherently, impact categories are not that easily defined, especially to draw the boundaries between different impact categories. In order to grasp the complexity of environmental impacts one distinguishes between *primary, secondary* and *tertiary* effects etc. A substance if released into the environment can have a primary effect that causes several secondary effects, which in turn another released substance is responsible for too. Furthermore, there can be feedback loops as well, altogether resulting in a cause-effect network or system rather than a simple cause-effect chain. (Baumann & Tillman, 2004).

LCIA deals with this by expressing potentials rather than actual effects, e.g., *global warming potential (GWP)*. Due to the complexity and uncertainty regarding environmental systems there are also several alternative characterization methods for many different impact categories. These can be seen as impact category subdivisions (see table 4.1). In general methods for more direct emission-cause impacts such as eutrophication, acidification and global warming are more developed than the ones that are more complex, such as resource use, land use and toxicity. This is also reflected in the number of different alternative subdivisions. E.g., in terms of resource use, one can distinguish between biotic and abiotic resources, renewable and non-renewable or deposits, funds and flows, whereas for eutrophication and acidification it is only a matter of terrestrial or aquatic (Baumann & Tillman, 2004).

Table 4.1. Examples of impact categories and possible subdivisions (Baumann & Tillman, 2004).

Impact categories (indicators)	Possible subdivisions
Resources	Biotic / abiotic Renewable / non-renewable Deposits /funds / flows
Land use	Occupancy / Land use change (LUC) Biological production Biodiversity Soil quality
Global warming	GWP 20 years / GWP 100 years / GWP 500 years
Ozone depletion	ODP∞ / ODP 10 years / ODP 25 years
Toxicity	Human toxicity potential (HTP) / eco-toxicity Aquatic / terrestrial Freshwater / marine
Photo-oxidant formation	Regional / local Photo-oxidant creation potential (POCP) / Incremental reactivity (IR) Maximum IR (MIR) / Maximum ozone reactivity (MOR) High-NOx POPCP / low-NOx POCP
Acidification	Terrestrial / Aquatic
Eutrophication	Terrestrial / Aquatic

4.3.2 LCIA methods

Existing LCIA methods vary in how they regard resource use as an environmental problem and what parameters that are included. LCIA methods can also vary in terms of geographical boundaries and scale (local, regional and global) but also in what time horizons that are chosen. In parallel, there can also be a lack of developed characterization models and or characterization factors for specific LCI parameters. In order to not neglect any such parameters one can either include specialized ad hoc characterization models or more basic assessments. LCA software very much simplifies the LCIA by providing several different ready-made LCIA methods to use. These methods differ in terms of calculation methods but also what impacts that are addressed, how they are prioritised and displayed (Baumann & Tillman, 2004; For a full list of the LCIA methods available in the software GaBi, see Appendix II: LCIA methods). The large variety of LCIA methods also reflect the complexity of assessing environmental issues. Both in terms of understanding environmental systems but also what we regard as important and what we in the end want to protect. It is also an area where there are lot of research is put in and more and more sophisticated LCIA methods are developed, including more possibilities to adjust the LCIA method to the specific goal and scope of the LCA studies. What is desired is also more general frameworks that make LCIA results more comparable and reliable (Baumann & Tillman, 2004).

5 Standards for environmental market communication

LCA results are not only used by businesses internally but also externally all along the product value chains for communication and market purposes. For those cases, it is important that the environmental information that is communicated is credible and intelligible but also possible to compare with other information from other sources. Therefore, there are standards not only for the LCA itself (i.e., the ISO 14040 series) but also for communicating its results (Baumann & Tillman, 2004).

5.1 Environmental product declaration (EPD)

ISO provides three types of environmental market standards depending on the type of communication needed: *Environmental labels (type I)*, *Self-declared environmental claims (type II)* and *Environmental declarations (type III)*, see table 5.1.

Table 5.1. Three types of environmental labels and declarations (CEN, 2018; 2016; 2010)

Type I	ISO 14024:2018	Environmental labelling: Principles and procedures
Type II	ISO 14021:2016	Self-declared environmental claims
Type III	ISO 14025:2006	Environmental declarations: Principles and procedures

In environmental market communication, one can distinguish between *business-to-business (B2B) communication* and *business-to-consumer (B2C) communication*. Businesses often have closer relations with each other as well as higher level of expertise and time spent on decision making, which implies a possibility of higher level of detail and technicalities to be included in the communication. On the contrary, this is more uncommon between business and consumers, which in turn requires data to be more aggregated and easily grasped. Hence, there is Environmental labels (type I) that help consumers distinguish between products that are more environmentally preferable than others while type III declarations, commonly referred to as *Environmental product declarations* (EPDs*)* are primarily used for B2B communication (Ibáñez-Foréz et al. 2016). Figure 5.1 further displays type I labels and type III declarations in the context of environmental market communication (Baumann & Tillman, 2004).

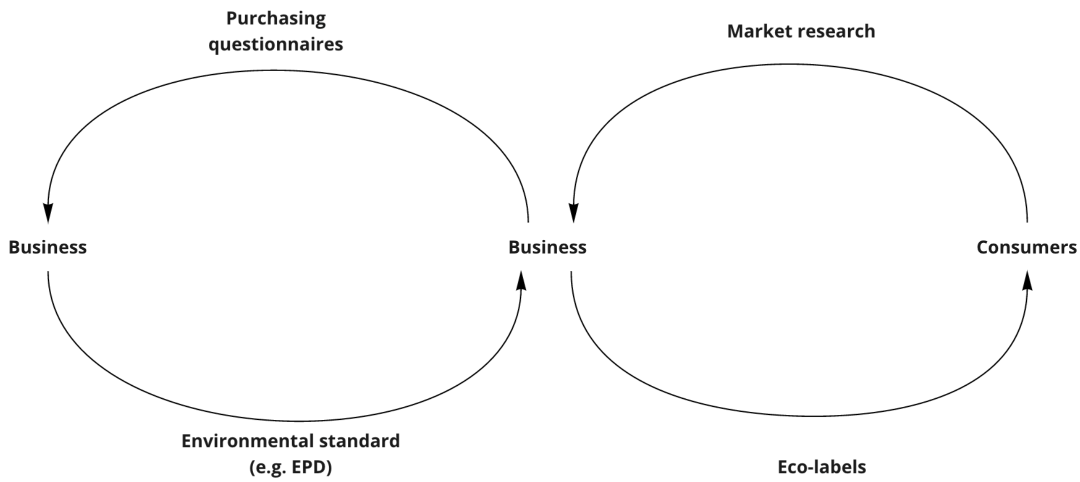

Figure 5.1. EPD and ecolabels in the context of environmental market communication (Baumann & Tillman, 2004).

ISO 14025 is more considered a technical document rather than a detailed standard, providing guidance in how to set up so called *EPD programmes (or systems)* in which EPD methodology and requirements can be described in more detail. Such programmes are today present in a variety of sizes and formats, targeting either products in general, more specific categories or organizations (Baumann & Tillman, 2004). As a company you produce an EPD within a *EPD programme* which in turn in is administrated by a *programme operator*. The programme operator is also responsible for the verification process, providing access to already published EPDs but also for developing product category rules (PCRs; Del Borghi, Moreschi & Gallo, 2020), which in turn specifies the required quantitative methods and communication formats for specific product categories (Husanger et al., 2014).

Perhaps the most recognized EPD programme is the *International EPD System* owned by *EPD International AB.* Originally, it was a national EPD programme for Sweden formed in 1998, that is now used by over 400 organizations in almost 50 countries worldwide (Del Borghi et al., 2020). The programme provides guidance and verification possibilities in publishing EPDs according to ISO 14025 and several other similar types of environmental declarations, including EN 15804 (EPD International, n.d.a),

5.2 Product environmental footprint (PEF)

There is a growing number of different EPD programmes available on the global market, each one including its own specific set of PCRs (Husanger et al., 2014), and companies on the European market need to adapt to several different environmental market schemes since countries have their own specific required EPD systems. Even if the national EPD systems are based on ISO 14025 or share similar PCRs, products may therefore need several different EPDs in order to be sold in multiple countries, which leads to additional costs for companies. In addition, when communicating environmental performance differently in different schemes, consumers are easily confused, which in turn undermines the trust of environmental claims (EC, 2013).

Therefore, there is a need to develop more general guidelines and declaration systems (Del Borghi, 2013) and to address this issue, the European Commission has communicated the *Single Market for Green Products Initiative,* which includes the *Product Environmental Footprint (PEF)* and the *Organizational Environmental Footprint* (*OEF).* These are proposed ways of measuring environmental performance of products and sectors (EC, 2013). They are based on the ISO 14040 series, ISO 14025 and the ILCD handbook, but aim to increase reproducibility, consistency, comparability, practicality by providing its own complete set of product and organizational environmental footprint category rules (PEFCRs and OEFCRs), as well as tools and databases (Sanne, 2021).

The development of PEF has been ongoing since 2008 (Humbert, 2019) and has consisted of several stages. In 2013 the PEF guide was released, including draft information on how to calculate a PEF and how to develop PEFCRs and OEFCRs (EC, 2013). From 2013 to 2018 there was the *PEF pilot phase,* where the first set of PEFCRs were developed. The PEF pilot included *scope and representative product definitions*, where typical products for each category were defined in detail; followed by *screenings* where simplified PEF methods were tested for the product categories in order to identify the most relevant life cycle stages, processes and impacts; then *supporting studies,* where the draft PEFCRs were tested for three or more existing products; and lastly *the approval of the final PEFCRs* (EC, n.d.a) after the closing of the PEF pilot phase.

The development of PEF is currently in the so-called *Transition Phase*, where the outcome of the pilot is analysed together with the development of some new PEFCRs (EC, n.d.b) and an assessment of the possibilities of implementing PEF in policy (Sanne, 2021; Eriksson 2021). Table 5.2 provides an overview of all PEFCRs developed during the pilot and transition phase.

Table 5.2. PEF product categories (PEFCRs) in the pilot and transition phase (EC, n.d.c; Sanne, 2020; Eriksson, 2021)

PEFCR	Finished in the pilot phase	Discontinued in the PEF pilot	Ongoing in the transition phase
Electronics	- Batteries - IT equipment - Photovoltaic electricity generation - Uninterruptible power supply		
Food production	- Animal feed - Beer - Dairy products - Olive oil - Packaged water - Pasta - Wine	- Coffee - Marine fish - Meat	- Marine fish
Housing	- Hot and cold-water pipe systems - Thermal insulation		
Industrial products	- Decorative paints - Intermediate paper products - Liquid household detergents - Metal sheets		
Textiles and clothes	- Leather - T-shirts		- Apparel and footwear - Synthetic turf
Other	- Pet food	- Stationary	- Cut flowers and potted plants - Flexible packaging

The development of PEF is administrated by the DG ENV and JRC together with a *technical advisory board* and a *steering committee.* The technical advisory board consists of approximately a hundred LCA experts that support in the formulation of detailed guidelines and principles. Specific areas, such as allocation, impacts and end-of-life treatment have been targeted using different working groups. The steering committee is instead a political body with representatives from countries, NGOs and industry, that is responsible for validating and approving the work done by the other parties (Humbert, 2019).

During the transition phase there are still two active working groups: the *Data working group* and the *Agricultural working group*. The data working group is responsible for the development of secondary data packages as well as setting up minimum requirements for software compatible with PEF as well as requirements for data quality and data communication, e.g., when data is considered outdated and how it then shall be updated etc. The agricultural group develops models on pesticide use, methane and nitrogen flows, fertilizers, water and biodiversity, which also makes it important regarding the PEFCRs related to food production. Models that specifically target resource depletion and dissipation are also developed. For the PEFCR for batteries e.g., the question is how to include circularity in the environmental footprint, something that has not been modelled in a high detail before. Questions that also remain for discussion in the transition phase are how to design the critical review process; how to administrate the PEFCRS and the PEF in the long term; how to relate PEF with EPD; which role will the EU commission have in the future; and how will the communication to consumers look like (Eriksson, 2021).

The fact that the development of PEF and PEFCRs is still an ongoing process opens up possibilities for companies and industry to get involved and influence the outcome and design (Eriksson, 2021). One channel to do this is through the *Swedish Life Cycle Center* (SLC), which has several representatives on the technical advisory board and can thereby provide a direct link to the PEF development process. During 2021, the SLC is running a project *called Environmental Footprint in Sweden that* aims to increase the knowledge about PEF in industry but also provide chances to influence the PEF development. During the year there will be a number of webinars and seminars but also expert meeting groups with representatives from industry (Palander, 2021). Two case studies will also be held in order to better understand the potential of PEF in Swedish industry. Companies involved are the steel manufacturer SSAB and the pulp and paper company Stora Enso (C. Larsson, 2021; L. Larsson, 2021).

5.3 Additional standards

In addition to EPD and PEF there is several other LCA related environmental standards. Many of which are focusing on carbon accounting and greenhouse gas (GHG) emissions, but there are also examples of standards and initiatives for eco-footprints as well as water footprints.

Carbon footprint standards

In terms of carbon footprint standards, the international standards organization (ISO) has provided two: ISO 14064 and ISO 14067. ISO 1464 specifies principles and requirements for greenhouse gas emission reporting while ISO 14067 concerns carbon footprints of products. It is similar to EPD (ISO 14025) but focuses exclusively on climate change where it accounts for land-use change, carbon uptake, biogenic carbon emissions and soil carbon change among others (PRé, n.d.; Sphera, n.d.). Similar to ISO 14067 there is the GHG Protocol for either products or corporations, developed by the World Resource Institute (WRI) together with the Business Council on Sustainable Development (WBCSD). Lastly there are examples of national standards such as the *PAS 2050,* which is the UK footprint standard providing GHG inventory guidance for companies, as well as the Carbon footprints standards of Japan and South Korea which are individual national standards partly based on PAS 2050 and ISO 14064 (Sphera, n.d.).

Environmental footprint standards

When it comes to certification and standards that account for more than just carbon, examples include *BPX 30-323*, which is a French environmental labeling guidance (Pré, n.d.); the *Ecologo*, which provides a wide range of product category specific standards for life cycle based environmental certification (UL, n.d.); the *EU Ecolabel* which is a EU environmental label for products, first introduced in 1992 and is targeting both B2B and B2C communication while also providing guidelines for companies to lower their environmental impact and in distinguishing eco-friendly best practices (EC, n.d.d); lastly, in 2010, the EU also published the so called *International Reference Life Cycle Data system (ILCD) Handbook*, which is a more detailed version and interpretation of the ISO 14040 series with more hands-on guidance for LCA practioners (EC, JRC & IES, 2010). This framework also made a foundation for the later development of PEF (EC, 2012).

Water footprint standards

Water footprint standards involve the ISO 14046 standard, which is an equivalent to ISO 14067 but for water. It provides principles, requirements and guidelines for calculating water footprints (CEN, 2014). There is also *The Water Footprint Assessment method, released in 2011 by the Water Footprint Network*, which provides water accounting methods for business, products and nations. It also makes the distinction between green, blue and grey water footprints which represents different elemental and technical water flows and stocks (Hoekstra, Chapagain, Aldaya & Mekonnen, 2011).

5.4 Conclusion: Standards

In short, there are a large variety of standards for environmental market communication available. What started with carbon reporting exclusively, has now also come to include a broader spectrum of impact categories, in efforts to acknowledge more ecological effects as well. This also includes water footprints. However, the large variety adds to the complexity of the situation. If you are a company, how to know which standard to use? Especially, when looking at the two predominant systems, PEF and EPD; what are the aspects of each system, how do they compare and what opportunities and limitations may they have for the company?

6 Method

The project consisted of three steps: (1) a mapping of the *current situation*, in terms of how the work surrounding eco-footprints is organized. Recognizing the needs of the involved actors, together with understanding the current practice; (2) a *standards evaluation* and comparison between EPD and PEF. This to determine what aspects of these standards that were important to acknowledge; and (3) *suggested improvements* to the work surrounding the eco-footprint, and by that fulfilling the aim and expected outcome of the work. However before diving into these steps, since this report involves the use of several different concepts surrounding LCA, some further clarification of the conceptual framework is first needed.

6.1 Conceptual framework

First, as mentioned in section 4, there is the *LCA method* and the *LCA procedure*, which are the components of an LCA study according to ISO 14040. Second, there is *Life Cycle Management* (LCM) which, as mentioned in section 3.3., is the organizational management that accounts for Life cycle thinking in business, i.e., it may involve LCA, however not exclusively. In this report, as a part of LCM, the concept of *LCA Practice* is used, which involves the LCA method and procedure as well as the organizational and aspects surrounding the work with LCA in general, i.e., the *LCA work process* (See figure 6.1). In addition, since *Eco-footprint* refer to the informal communication format of environmental performance data at Nouryon described in section 2.3, what is referred to as the *Nouryon eco-footprint methodology* is therefore a documented LCA practice surrounding the Nouryon eco-footprint.

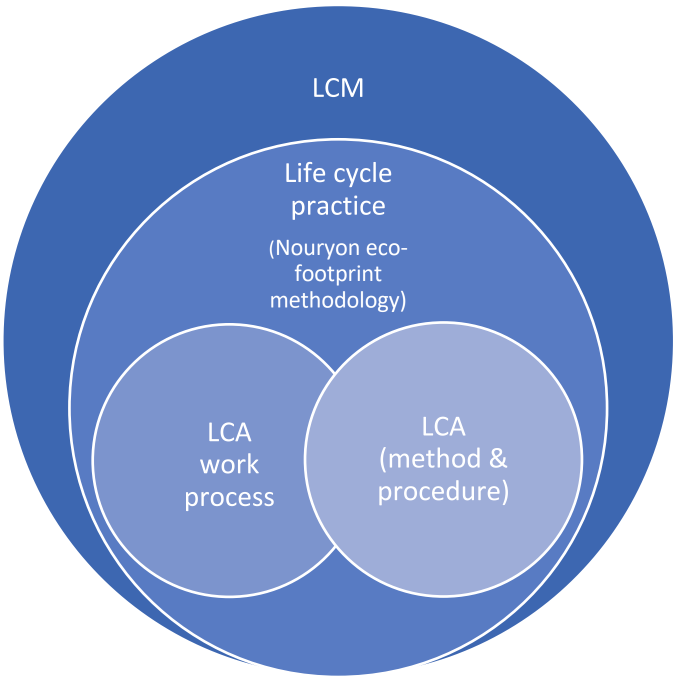

Figure 6.1. Conceptual framework used.

6.2 Exploring the current situation

For this part, several different approaches were taken. First, relevant stakeholders were identified, foremost members of the sustainability team and their interrelations with other actors in and outside the company. Meetings were then held on how the eco-footprints process is experienced: what is working well and what is not; what bottlenecks there are, in terms of e.g., time and resources; what should be included in a future work process etc. Second, was to get a sense of how LCA and eco-footprints are usually carried out, by identifying aspects such as: how allocations are made; how system boundaries are considered; how the results are communicated; what data that is used; what impact categories that are used; how results are communicated etc. Furthermore, it also included getting familiar with the software used and how data collection can be carried out. This was done by working with a case, updating the LCA models for the ethylene oxide (EO) and ethylene amine plants (EA) in Stenungsund.

6.3 Standards evaluation

Here a literature review was conducted to compare the aspects of EPD and PEF, followed by a SWOT analysis, determining how these aspects relate to the current practice and prerequisites at Nouryon, found in first step.

6.3.1 Literature review

Environmental standards in the context of this study were any documentation regarding how to interpret and apply the ISO 14040 series and communicate the results of such studies. However. focus was exclusively laid on comparing EPD and PEF, since these represent the two most acknowledged and extensive standards for environmental market communication there are.

The collection of reference material was mainly carried out using a snowball sampling approach (Goodman, 1961) combined with a literature review, where initial reference material was used in order to identify new information and sources. For EPD, initial information was found in standard documents provided by the Swedish Institute for standards (SIS, n.d.) as well as course literature and scientific literature using *Google Scholar* and the *Chalmers library* literature database. Regarding PEF, the European Commission website and the *Single market for Green Products Initiative* was a good starting point as well as scientific literature comparing EPD and PEF. Since the development of PEF is an ongoing process and the documented references available are limited, useful sources of information also proved to be newly recorded webinars held by LCA software and database providers as well as the *American Center for Life Cycle Assessment* (ALCA). A webinar on PEF held by the SLC was also attended live in the end of March (SLC, 2021).

6.3.2 SWOT analysis

SWOT analysis was used in order to both compare different aspects of PEF and EPD but also to identify aspects that could be important to incorporate in the eco-footprint.

Developed in the 1960s (Sevkli, 2012), SWOT analysis is a decision-making support tool that in a systematic way helps determine the strengths, weaknesses opportunities and threats related to an internal or external environment, so called *strategic factors.* The results are often displayed in a *SWOT matrix,* as seen in table 6.1 (Kotler, 1998 & Wheelen & Hunger, 1995 as cited in Kangas et al., 2003).

Table 6.1. SWOT matrix

	Positive	**Negative**
Internal	Strengths	Weaknesses
External	Opportunities	Threats

Based on the results, strategies can be developed that account for both negative and positive, as well as internal and external factors (Kotler, 1998 & Wheelen & Hunger, 1995 as cited in Kangas et al., 2003). Positive factors can either be used, shared, increased, or ignored, while negative factors should be avoided, moved, reduced or accepted. Having strengths and opportunities that matches weaknesses and threats together with acknowledging any gaps and propose strategies for those, increases the overall robustness. (Tonnquist, 2018).

Traditionally in strategic management, external factors ARE categorized into *Economic factors*; *Social and political factors*; *Products and technology*; *Demographic factors*; and *Markets and competition,* while the internal environment is represented by *Management and organization;* and *Operations* and *Finance* (Weihrich, 1982). Other examples are found in project management where internal factors are defined as the ones that can be directly influenced by the project owner and team, whereas external involves other stakeholders as well (Tonnquist, 2018). Furthermore, in ecosystem science, strengths and weaknesses have been linked to a specific object or system of study while opportunities and threats may arise from the outside world (Bull et al., 2016).

When it comes to LCA, SWOT analysis is sometimes applied as an add-on tool. Examples are the *Sustainability SWOT* that uses the LCA results to determine strategic factors that are in turn categorized as either *environmental*, *social* or *economic* (Pesonen & Horn, 2013). In similar ways strengths and weaknesses have been defined as impact categories of lower or higher contribution respectively, and opportunities and threats as solutions or limitations for improving the environmental performance of the product system of study (da Luz et al.,2018). Furthermore, there is the *Climate SWOT,* which distinguish between current (i.e., strengths and weaknesses) and future (i.e., opportunities and threats) environmental impacts that are either positive or negative for climate mitigation (Pesonen & Horn, 2014).

The distinction between strategic factors is therefore not that clear and varies between different fields and studies, especially the distinction between internal and external factors. From these examples, it involves at least two elements: (1) *space,* where internal factors are found within a closed system that is under the direct influence of the ones conducting the SWOT analysis. External factors are found outside the closed system and cannot be directly controlled. (2) *Time*, where internal factors are current whereas external are future and are potential rather than existing. Using LCA terminology the space element may reflect the distinction between foreground (gate-to-gate) and background (upstream and downstream processes) systems where strengths and weaknesses are factors that are controlled by the own organization. Similarly, time could reflect the difference between attributional and change oriented LCA, but it is also important to identify what is known or not (so called known unknowns).

In this study, the findings from the sustainability organization mapping and the identification of environmental standards were combined in order to identify strategic factors. In the end, distinguishing between what is positive and negative factors is more important than what is internal and external. Even more so, acknowledging the strategic factors in the first place (Tonnquist, 2018). Still, any identified strategic factors are distinguished between strengths, weaknesses, opportunities and threats, which considers the elements of space and time in the following criteria.

Aspects of environmental market standards that …

- (Strengths) align with current LCA practice
- (Weaknesses) do not align with current LCA practice
- (Opportunities) may align with current LCA practice
- (Threats) may not align with current LCA practice

Align means that there is no conflict between what the standard says and what is practiced today at the company. Furthermore, *may* suggests that the prerequisites are not yet fully determined and there is a high degree of uncertainty regarding the implications of specific aspects.

The results are then displayed using SWOT matrices or similar descriptive tables, together with a more thorough description and elaboration of each strategic factor.

6.4 Suggesting improvements to the Nouryon eco-footprint methodology

Here a discussion regarding the work process in general is included as well as the goal and scope definition; suggestions on the LCA method and lastly a proposed format for communication of the results. This was based on the findings in the previous sections, describing the current situation and the evaluation of EPD and PEF, i.e., how can the areas of improvement be approached and how can relevant aspects of PEF and EPD be. Some suggestions have been developed in close dialogue with involved actors, others are provided from literature.

6.5 Ethical implications

When it comes to assessing and communicating environmental performance and LCA results, companies are ethically obliged to present truthful and accurate data. However, phenomena such as *green washing* do still occur, where companies tend to exaggerate environmental performance in order to favor marketing and competitiveness of their own products. This is partly the reason why standards exist in the first place, so that products from different manufacturers can be compared on an equal basis. Still, there is not yet any standard that is both universal while still is providing enough level of detail to be applicable for many kinds of product categories. PEF, which is still under development is perhaps one of the closest things we can get to something like that so far. In the meantime, companies can pick freely from a large variety standards, methods and labels which compromises comparability and consistency, and increases the risk of both intentional and unintentional publications of misleading data. These implications are of high relevance to this work and should therefore be acknowledged.

7 Current situation

Here are the findings regarding the current organization and work surrounding eco-footprints at Nouryon.

7.1 Actors

As first mentioned in section 2, Nouryon consists of three different businesses: Performance Formulations, Technology Solutions and Nobian (formerly Industrial Chemicals). These businesses represent three different market branches, each with individual sets of research and development (R&D) departments as well as market and sales. However, there are additional supporting branches including the *Integrated Supply Chain* in which the production sites and manufacturing are found. As a small supporting branch there is also the central sustainability team, responsible for the sustainability agenda as well as the work surrounding LCA.

Figure 7.1 illustrates the relation and communication pathways between all mentioned actors. The sustainability team consists of the Chief Sustainably Officer, the Sustainability director as well as a couple of sustainability specialist, experts, but also consultants. These are the ones that conducts LCAs and are managing the LCA database. All three businesses also have sustainability managers/product stewards that work in close collaboration with the sustainability team, acting as gatekeepers and focal points to the rest of the organization.

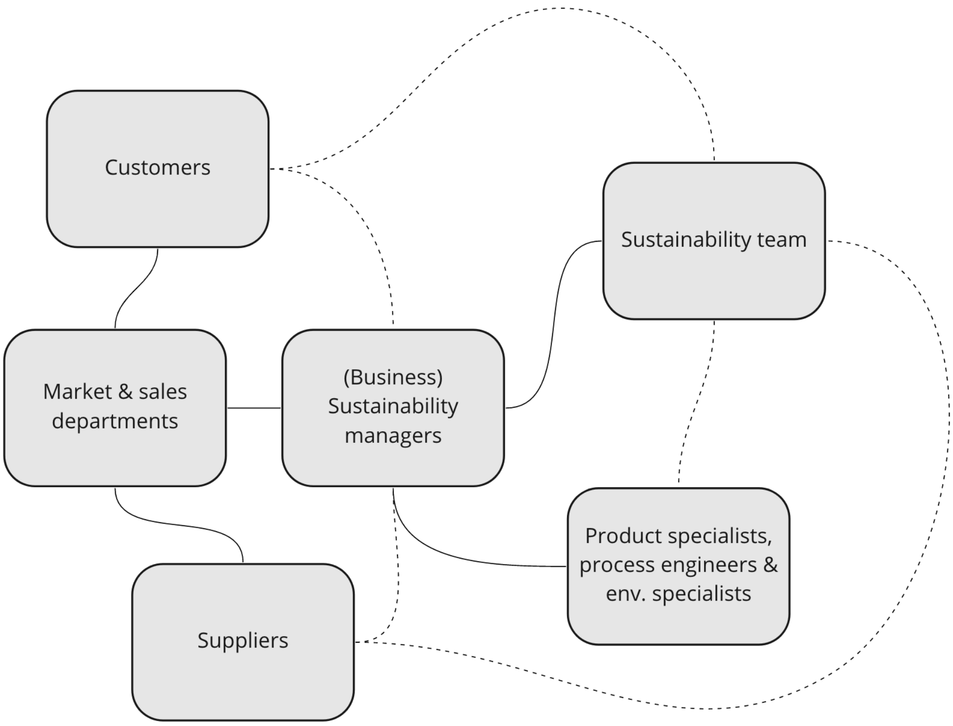

Figure 7.1. Actors involved in the production eco-footprint and their formal (solid) and informal (dashed line) communication pathways.

The production of eco-footprints involves primarily the sustainability specialist of the central sustainability team and the sustainability managers of each business, but it also includes some actors:

Customers

- which initiates the request of environmental data and specifies the demand.

Market and sales departments

- having the closest contact with customers and suppliers.

Process engineers and environmental specialist

- having access to site-specific data and expert knowledge about processes and products.

Suppliers

- having access and knowledge about upstream specific data, products and processes.

7.2 Work process

Figure 7.2. Swimlane chart describing the work and decision process surrounding eco-footprint It is very much a dynamic process, that varies from case to case. The communication between parties is also very much interlinked and not always straight forward.

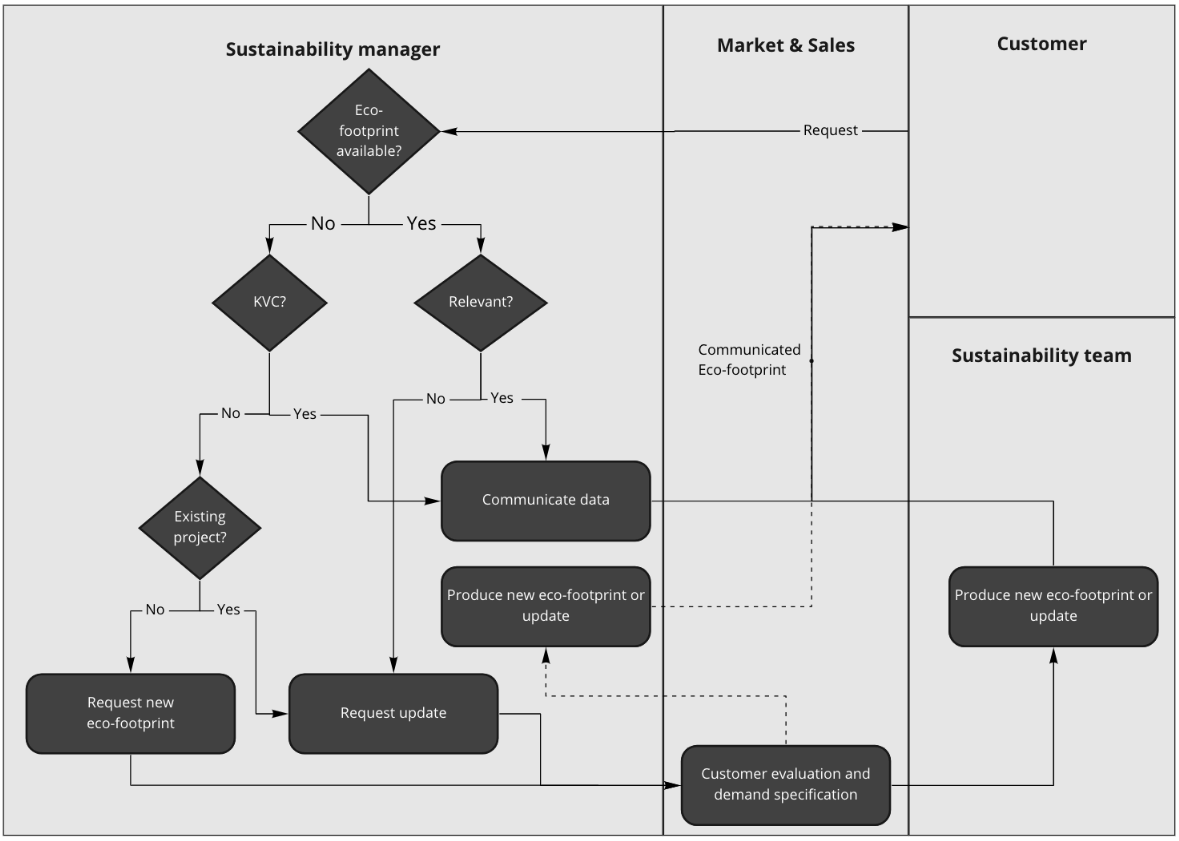

Figure 7.2. Swimlane chart describing the work and decision process surrounding eco-footprints (tilted squares and rectangles are questions faced and processes while arrows are the process flows. Solid primary and dashed secondary ways to proceed).

The process is initiated by a request to market & sales department from a customer and is passed on to the Business Sustainability manager. There are three types of environmental performance data that may be used: best case scenario is if there is already an existing eco-footprint for the product in question; second if there is an eco-footprint or carbon footprint carried out for a KVC that could act as a representative product instead; or third if there is any relevant ongoing LCA project in the GaBi database, i.e., there is LCA results available that could be used for an eco-footprint. All these steps involve a close dialogue with the product specialist and the customer in order to determine if it is data that is sufficient and there are a few different aspects that may be considered. E.g., If it is data for the product itself or a close related one and how closely related in such case, if there are any impacts categories missing or questions about the methodology. A customer may e.g., carry out an EPD on its own, according to a specific standard and therefore having strict demands on what type of LCI and LCIA methodologies to use. There is also the aspect of time and if the data is still valid, something that needs to be determined by the customers since there is no validity or expiration dates set by default for eco-footprints.

If there is no data available at all or if there is but it needs to be updated or complemented in some way, important is to, before initiating any new LCA projects, formulate a demand specification together with the customer. This is necessary in order to know what to produce but also in order to be able to estimate the costs and time needed: if it is an easier task that can be carried out by the Business Sustainability manager over a few days, or if it something that the central sustainability team must do, which also requires budget approvals from higher management levels. It also involves evaluating the customer, since environmental performance data may include confidential information only worth sharing with significant customers. Here it has been requested to have a more straight forward decision process since it is not always clear who is responsible for carrying out the potential LCA and how much resources should be spent on it. Lastly when the new eco-footprint or updated version is complete, it is communicated to the customer through the market and sales department.

7.2.1 LCA software and data management

The LCA software used is GaBi. LCA models are built up in so called *plans* that includes all relevant processes and flows. Plans are often product specific, which means that allocations are done before adding values to the flows. The final product output also only consists of the product of interest. If doing multiple LCAs of products that are produced by the same processes, identical plans are created, but the flows vary depending on the allocation resulting in different environmental impact.

An important part of the LCA practice is the management of the common database. The database is found in GaBi and includes all LCA projects that is currently or have previously been carried out, as well as internal and external processes, flows and parameters. All members of the sustainability team have access to it, as well as some outside such the business sustainability managers, but it is primarily administrated by one in the core team. Furthermore, since the database file itself cannot be shared or saved simultaneously, all people that are using it downloads a copy of the so-called *master database* and when they are finished with their project, they send that file to the administrator that updates the master database and saves the old one as a copy.

Some issues related to the database management were identified during the project. First, the overall size of the database had during the latest year almost doubled in file size from being at a rather constant level, leading to a slower experience working with the database. The reason why was unclear when talking to the members of the sustainability team. When also establishing contact with the software provider Sphera, they did not have any obvious explanations why either. Suggestions regarded the so-called balances, which are saved LCIA documentation. Also, to clear the tracking history. Neither of these issues seemed to be key however, and due to time limitations there was no opportunity to dig into this matter further.

Second, the way things are categorized in the database is partly based on the company organization structure, e.g., folders are named and sorted after businesses and product lines. However, due to past reorganizations some parts of the database structure are no longer representative. E.g., old business names are used. For more experienced users this is no problem, since the structure is familiar, and all the old names are known. Making any changes would rather make it difficult to find the right things. However, for more recent members of the sustainability team, including hired consultants or students that are carrying out LCAs may have a harder time understand the structure and find the right things. Leading to a heavier dependence on the more experienced members and therefore increase their workload indirectly.

Third, there seemed to be a discrepancy in the naming of database folders and objects, contributing the confusion surrounding the database structure, where to find things but also when creating new objects. It turned out that there are guidance documents available, but few knew that they existed or where to find them.

7.3 LCA method

The following sections describes the LCA method applied when producing or updating an eco-footprint.

7.3.1 Goal

The indented use of eco-footprints is primarily for communicating environmental performance of products to customers. Therefore, LCAs are normally attributional, using retrospective data. The communication is done through three different formats:

1. Carbon footprint, where only a value for CO2 equivalents per functional unit is given, often communicated informally by e.g., email-conversations.

2. Eco-footprint, where several impact categories are reported. Either informally communicated or using a template similar to an EPD.

3. Full EPD, which includes a large number of impact categories, passing a review and making it available for the public.

Which type, is determined by what the customer demands and how important the customers regarded, since moving towards eco-footprints or full EPDs require more work, costs and leaving out confidential information.

7.3.2 Scope

Functional unit

The functional unit is by default 1 metric ton product.

System boundary

Although the targets for carbon reporting in the sustainability report covers only scope 1 and 2, i.e., gate-to-gate plus energy production, more extensive eco-footprints that have been carried out are also including scope 3 (raw materials) and is therefore cradle-to-gate. Furthermore, full EPDs also include transport of the finished product.

Natural boundary

In terms of the natural boundary, relevant parts concern raw material extraction, use of renewable energy and resources and emissions to air water and soil. However, any clarification of natural boundaries is not included in eco-footprints, and it is unclear if there are any considerations taken at all.

Geographical boundary

In terms of scope 2, the geographical boundary is most often site-specific. Similar production plants around the world with similar material and energy requirements may benefit from having similar LCA models created, in order to boost efficiency and comparability. Still, the data used is site-specific and the generic data is if possible regionalized.

Cut-off criteria

Examples are personnel, machinery, maintenance, laboratories but also chemicals e.g. additives that are used in small quantities.

Time horizon

Eco-footprints are only dated but include no specified validation time.

Data quality requirements

Eco-footprints state only that specific data is used when available.

Assumptions and limitations

Eco-footprints do not state any additional assumptions and limitations

7.3.3 LCI

Here follows the findings regarding the LCI, including data collection and allocation.

7.3.3.1 Data collection

The real upside of the chemical industry regards the availability of primary data. Many process and emission flows are continually monitored for the purposes of production or governmental reporting and stored using a *Manufacturing execution system* (MES). Most relevant environmental data is summarized in environmental reports which are produced annually and in terms of raw materials and products, there is the so-called Bill of materials (BOM) which is a sort of production recipe. Collecting primary data also involves close contact with local experts such as process engineers and environmental specialist in order to access more detailed data but also understand the system better. Secondary data is required for electricity, transport and production of raw materials. Here the company has its own database constructed for previous studies. Otherwise reference data is gathered from Ecoinvent, other LCI databases or from direct contact with suppliers.

In the case work, collecting data for the EO and EA plants in Stenungsund, the above-mentioned sources were used. Representatives on-site were primarily two process engineers. From this process there were some important insights. First, it turned out to be rather difficult to determine what data to ask for. An initial approach was to look at the older models in GaBi, including flows and processes, but they did not fully match the reality. E.g., flows mentioned did not exist and flows that did exist were not included. Second, the process engineers were glad to help but questioned the long period since the models were last updated. This is understandable, if working continuously with improving process and environmental performance on-site, but still the models used for calculating that performance and acknowledging the work is updated with up-to ten years apart.

7.3.3.2 Allocation

Allocation problems are very much present in the chemical industry. Most chemical production involves multiple input and out-processes that are linked in complex ways. One chemical plant may produce over a hundred different products. Major allocation problems also regard steam and wastewater. Figure 7.3 illustrates a very much simplified conceptual model of a typical chemical production site. Here it includes two different plants, a boiler, a wastewater incineration facility and a wastewater treatment plant. Plants including reactors are often *closed* and have no direct emissions to air except for security venting. Waste is instead transferred by water to incineration or treatment, thus the emissions arising from the combined production of waste are measured at the chimney of the wastewater incineration facility or the outlet at the wastewater treatment plant. One approach to this is to first determine what emissions may be generated form the product of interest. Second, distinguish all other product that may generate the same type of emissions; and third, allocate e.g. By mass between these products.

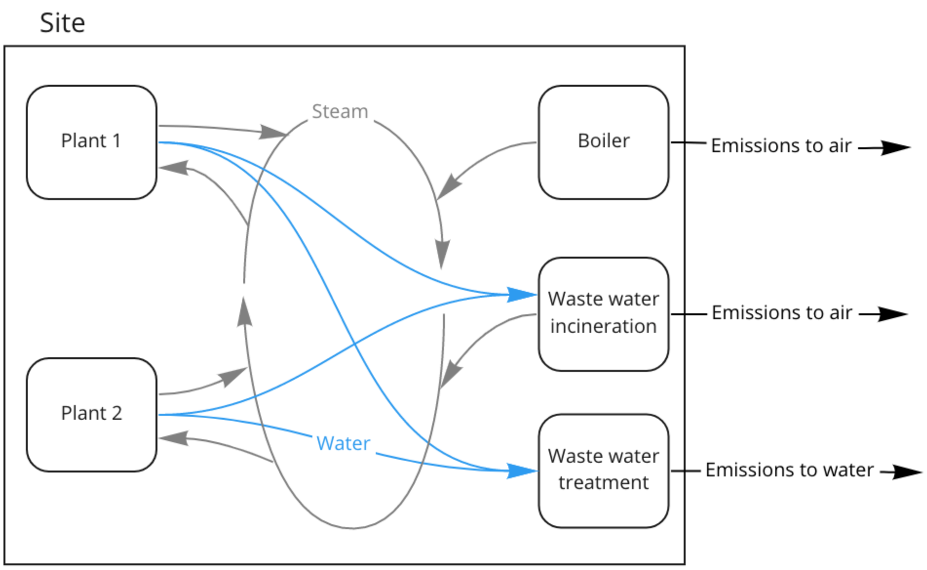

Figure 7.3. Conceptual model of the water and steam flows at a chemical site.

Furthermore, there is the production of steam, which is used as an energy carrier heating up reactors, distillation towers etc. Steam is generated in boilers using, natural gas or oil, in the wastewater incineration facilities, but also in the reactors themselves since many chemical reactions are exothermic and produce excessive heat. The steam is distributed and recirculated using a combined network that covers all, or parts of, the site. How this is normally approached is using credits and system expansion, i.e., Products are accounted for the steam required but also credited for the steam that is produced. In processes having several product outputs, this also needs to be combined with some sort of mass, economic, or energy allocation method.

7.3.4 LCIA

The LCIA itself is carried out by a calculation done by the LCA software. Specific LCIA methods can be chosen based on the request of customers or the communication format. By default, for eco-footprint the CML 2001 method is used, and the impacts categories are [with equivalent unit]:

- Global warming potential (fossil and biogenic) [kg CO2]
- Ozone depletion [kg CFC-11]
- Acidification [kg SO2]
- Photochemical ozone creation potential [kg ethene]
- Eutrophication [kg PO4(3-)]
- Depletion of abiotic resources (elements and fossil) [kg Sb, MJ]

No further weighting, normalization, grouping or data quality analysis is normally done.

7.4 Current eco-footprint format

The template starts with a title and date, followed by a short description of what the eco-footprint is and how it is based on LCA. Also, if any specific methods are applied e.g. In accordance with a specific PCR in an EPD programme or environmental standard such as e.g., EN 15804.

The following sections are:

Product description

which specifies the applications and properties of the product in question.

Presentation of environmental performance

which is a short description of the scope including applied system boundaries, a flowchart, geographical boundaries, data requirements and allocation.

About Nouryon

Description of markets, history, number of employees and countries present.

Eco-footprint results

Given per functional unit and includes: (1) A list of the required resources and the total use of renewable and non-renewable so called primary energy resources (original energy resource e.g. Crude oil or biomass) as well as use of secondary materials and secondary fuels; (2) The LCIA results with the impact categories listed in the previous section; (3) The most important emissions to air and water, including carbon dioxide, methane, non-methane volatile organic compounds (NMVOCs), sulfur dioxide, nitrogen oxides, chloride, sulfate, nitrate and sodium; and (4) Waste generation: hazardous, non-hazardous and radioactive.

Glossary

Describing the different concepts mentioned in the eco-footprint.

7.5 Conclusion: Areas of improvement

To conclude, there several things that may be addressed in order to increase the efficiency regarding eco-footprints. First, concerning the work process, there is a lack of a clear work structure and decision process. This have complications in terms of e.g., knowing what people to involve, what things to do in what order and what resources that should be invested. Second is the data management, where experienced problems relate to the size of the database and how folders and objects are named and structured. Third, there is the data collection which is heavily dependent on personal communication and thereby suffers risks of misinterpretations, delays and incomplete data, especially concerning descriptive data. Lastly, regarding allocation, the chemical industry is highly complex, and even if there is much primary data available the question remains on how to carry out allocation in a feasible, still realistic and relevant manner. The following chapter will also help determine if there are any things related to the LCA method and ecofootprint that may be improved.

8 Standards evaluation (SWOT)

Here the aspects of PEF and EPD has been evaluated based on the findings in the previous chapter, and a number of strengths (S), weaknesses (W), opportunities (O) or threats (T), related to the two different environmental standards have been identified.

8.1 Intended use

Here the intentional use of LCA at Nouryon is compared with the ones of EPD and PEF. The question of how LCA is carried out in the two systems will be discussed in the following section.

EPD is primarily intended for external B2B communication, but proposed uses are also B2C communication as well as for green public procurement (del Borghi et al., 2020). Potential use of the PEF method is in-house applications such as supporting environmental management, identifying environmental hotspots or improve environmental performance, as well as external communication, including both B2B and B2C communication. This in turn, suggests possibilities for marketing, answering customer demands of environmental data, environmental labeling, supporting eco-design throughout value chains, green public procurement and following environmental legislation that includes PEF (Allacker et al., 2014).

As for Nouryon, there is the fact that EPDs are already used today. However, as a communication format it is considered quite time and resource consuming and is only carried out if a high value customer is asking for it explicitly. In most cases environmental data is instead communicated informally without any review or standardized reporting format. Neither EPD nor EF provides a lighter version for informal communication. Even if the intended applications of PEF seem to be similar to EPD and therefore fitting the LCA practice as well, all potential uses and the real applications are not yet clear or determined, especially for products that have not yet been addressed in any PEFCR.

8.2 LCA method

So far, the required LCA method of PEF can be found in the PEF guide from 2013. Studies have compared these requirements with the corresponding EPD requirements of the International EPD System, the so-called *General Programme Instruction (GPI) key rules* (see table 8.1). There are a number of clear discrepancies between PEF and EPD and the overall comparability between the PEF guide and the GPI key rules are considered poor.

Table 8.1. Comparison between the LCA method criteria in the PEF guide and the IES GPI key rules (Del Borghi et al., 2020).

Criteria	***PEF guide***	***GPI rules***
Functional unit	*Unit-of-analysis* (including quality and time)	*Functional unit, FU*
System boundary	Cradle-to-grave and *foreground*- and *background processes*.	Cradle-to-grave and *upstream*-, *core*- and *downstream processes*.
Modelling approach	Attributional and consequential	Attributional only
LCI	Resource use and emission profile (RUaEP); Data collection template provided, Screening recommended, Data management plan.	Life cycle inventory
Cut-off	Not allowed, but exceptions may be present in specific	Allowed but limited to 1% as maximum
Allocation	Process subdivision, system expansion, based on physical or other relationships and a provided recycling allocation formula calculating the Resource Use and Emissions Profile (RUaEP).	Process subdivision, based on physical or other relationships, polluter pays (PP) allocation method for reuse, recycling and recovery.
Data quality	Specific data is recommended. Exclusive generic data sources. Generic data up to representing 10% overall impact of the product system. Data quality assessment. "*Good quality*" specific and generic data must represent at least 70% of each impact category.	Specific data is mandatory for core processes. Generic data must fulfil predefined characteristics. Proxy data for up to 10% of the overall impact of the product system. A specific data declaration is recommended.
Impact categories	Default set of impact categories. Normalization recommended Weighting allowed	Default set of impact categories Normalization allowed Weighting allowed

Here follows a more in-depth overview of the stages in LCA application and how it is approached in PEF and EPD.

8.2.1 Scope

Starting with the functional unit, which in the EPD system aligns well with ISO 14040, since it describes the function or service ("*what?*") and the quantity ("*how much?*"), while in the PEF there are two additional components: quality ("*how well?*") and time ("*how long?*") which are required in the so-called *unit of analysis*". Both the functional unit of EPD and the unit of analysis are however similar in their relation to the defined reference flow of the product system (Del Borghi et al., 2020). In terms of Nouryon there is no conflict with the way the functional unit is defined in EPD, however adding the dimensions of time and quality to the functional unit using PEF, would be something new to the current LCA practice.

In terms of system boundary, the two systems take different approaches. EPD distinguishes between *upstream* (cradle-to-gate), *core* (gate-to-gate) and *downstream* (gate-to-grave) processes, while PEF add the distinction between *foreground* or *background* process as well. Foreground processes are core processes where also data is directly available, while background processes are processes where data must be gathered from secondary sources (Del Borghi et al., 2020). As for Nouryon, Scope 1 and 3 matches the downstream and core processes of EPD and the foreground and background processes of PEF quite well. However, both PEF and EPD lack a clear equivalent to scope 2, which only represents energy use.

The distinction between foreground and background processes (so called *subdivision*) is especially useful for change oriented LCA studies in general (Baumann & Tillman, 2004). This also reflects the difference in modelling, where EPD takes only an *attributional approach*, I.e., specific and average data is used but not marginal data while PEF uses a mix of both attributional and consequential data (Del Borghi et al., 2020). In terms of Nouryon, LCA studies generally takes an attributional approach which fits the EPD method well. As for PEF, it is still somewhat unclear how both an attributional and a consequential approach will be applied for specific PEFCRs, and what implications this may have on Nouryon. Complexity may arise but also new opportunities for carrying out LCA and for new purposes.

8.2.2 LCI

When it comes to what is included in the LCI on a general level, PEF and EPD are quite similar. Material, energy, resource use and outputs must be included, along with emissions to air, water and soil. The difference is that in PEF this is referred to as the R*esource Use and Emissions Profile (RUaEP)* instead of an LCI. The PEF guide also provides a data collection template, it recommends a screening step and suggests that a data management plan is developed (Del Borghi et al., 2020). As for Nouryon, the terminology and components of the EPD regarding LCI is familiar and the way it is changed in PEF may lead to some confusion. However, providing more guidance in how to collect and manage data may be something that makes the process more efficient but also more comparable with other studies, both within and outside the company.

EPD allows for cut-off criteria if it does not represent more than 1% of the total environmental impact (Del Borghi et al., 2020). In the PEF guide it is however stated that cut-off criteria are not allowed (EC, 2012). This would be hard to apply by Nouryon which usually neglects environmental impact from machinery and personnel etc. due to the high level of complexity in relation to the estimated environmental impact of such activities. The PEF guide was also criticized for this early on (Finkbeiner, 2014) but it was also further clarified by the Directorate General for the Environment (DG ENV) of the European Commission and the Joint Research Centre (JRC) that the cut-off rule is compensated by an allowance for lower quality data. The principle is that it is better to use data available than making assumptions and thereby neglect data even if it is of low quality (Galatola & Pant, 2014). In addition, now after the pilot phase, it has also been further clarified that cut-off are not allowed during screening, but once the PEFCRs are prepared, they can in turn allow for specific cut-off methods. Therefore, it is still unclear how this would affect the practice at Nouryon.

In terms of allocation, for EPD, allocation problems must be solved by conventional allocation methods and not by using e.g., credits or avoided emissions by system expansion (Del Borghi et al., 2020). This is problematic for Nouryon since credits and system expansion has proven to be a way to account for e.g., steam generation that occurs in reactors and wastewater incineration facilities. PEF on the other hand, which is combining both an attributional and consequential approach, allows for system expansion (Del Borghi et al., 2020), which may be favorable for Nouryon. PEF is however also proving own allocation formulas e.g., Regrading recycling of materials instead of using polluter pays (PP) allocation methods as in EPD (Del Borghi et al., 2020) and what effects this may have is unclear.

8.2.3 Data quality

In terms of data quality requirements, PEF and EPD share several similarities but have also differences. In both EPD and PEF specific data is primarily to be used for core and foreground processes respectively. However, while IES prohibits use of generic data if specific data is available, PEF instead recommends use of generic data if it can be proven to be more representative and appropriate than the available specific data (Del Borghi et al., 2020). As for Nouryon, site-specific data is preferably used for internal processes which corresponds with the requirements of PEF and EPD. However, data for similar production facilities in different countries are sometimes shared which may come in conflict with the stricter requirements set by EPD. PEF may be more tolerant for such circumstances.

When using PEF, 70% of the specific and generic data used for every impact category must be considered as of *"Good quality"*. This is determined by an evaluation scheme that includes an assessment on technological-, geographical- and time -related representativeness, completeness, parameter uncertainty, methodological appropriateness and consistency (Del Borghi et al., 2020). Assessing both generic and specific data, as required by PEF, has been argued would require a much heavier workload and additional costs without affecting the quality significantly (Finkbeiner, 2014). IES on the other hand only requires a similar assessment and criteria for generic data. Generic data that fulfill predefined characteristics for technological-, geographical- and time -related representativeness, precision and completeness is called *selected generic data.* Other generic data that does not fulfill the requirements is instead called *proxy data*. The reason behind this distinction is that proxy data is allowed to represent a maximum 10% of the overall impact of the product system. The rest must be either specific or selected generic data. In terms of specific data, IES instead recommends a declaration of the contribution to the overall environmental impacts arising from specific data (in %) to be included (Del Borghi et al., 2020).

Lastly, while IES allows generic data from any source PEF requires generic data from a limited number of data sources, including the ILCD data network, ELCD, PEFCR compliant data and data from other PEF studies (Del Borghi et al., 2020). The upside of using a limited set of data sources is increased simplicity but this presumes that all necessary and relevant data is available and of sufficient quality. Otherwise, there is a risk of missing out or simplifying important environmental aspects (Finkbeiner, 2014)

8.2.4 LCIA

As for Nouryon, the GaBi software has been used for carrying out EPDs previously, but the LCIA methodology of PEF is also supported (Sphera, n.d.b) which suggests that any implementation of PEF can be carried out without any major technical difficulties. Both IES and PEF provide individual default sets of midpoint impact categories, which in turn may be complemented in PECRs or PCRs respectively. As seen in table 8.2, categories that share the same characterization models are climate change, photochemical ozone formation, abiotic depletion and water scarcity, while the ones that are different are foremost acidification and eutrophication. However, even if the same original model is used there may be differences due to changes and adaptations (Fazio et al., 2018; IES, 2018). Noticeable is also the greater number of impact categories set as default in PEF compared to in EPD. Still in EPD, additional impact categories are recommended to use and may also be included as mandatory in specific PCRs (IES, 2018).

Table 8.2. Default impact categories and their characterization models in PEF (Fazio et al., 2018) and the international EPD system (EPD International, 2018).

Impact category	**PEF**	**EPD**
Climate change	IPCC 2013	CML 2001 [IPCC 2013]
Acidification	Accumulated Exceedance [Seppälä et al., 2016 & Posch et al. 2008]	CML 2001 non-baseline (2016) [Hauschild & Wenzel, 1998]
Eutrophication	Terrestrial: Accumulated Exceedance [Seppälä et al., 2016 & Posch et al. 2008] Aquatic: ReCiPe (Struijs et al., 2009]	CML 2001 baseline (2016) [Heijungs et al., 1992]
Photochemical oxidant (ozone) formation	ReCiPe 2008 [Van Zelm et al., 2008]	ReCiPe 2008 [Van Zelm et al., 2008]
Abiotic depletion (Resource use; ADP)	CML 2001 [Van Oers et al., 2002]	CML 2001 [Van Oers et al., 2002]
Water Scarcity Footprint (WSF)	AWARE 2016* [UNEP, 2014]	AWARE 2017 [Boulay et al., 2017]
Land use and land use change (LULUC)	LANCA [Beck et al., 2010 & Bos et al., 2016]	
Ozone depletion	WMO, 1999	
Ionizing radiation	Frischknecht et al, 2000	
Human toxicity	USEtox (Rosenbaum et al, 2008)	
Ecotoxicity	USEtox (Rosenbaum et al, 2008)	
Particulate matter (PM)	UNEP 2016	

It has been argued that some of the introduced methodologies used by PEF are quite uncommon and not scientifically recognized by the LCA community. Something that questions the overall credibility of the PEF methodology (Finkbeiner, 2014). Other critique has been that the default models lack some important environmental areas such as e.g., biodiversity. There is also a lack of characterization factors for some vital elementary flows, including emissions of chemicals into nature (Vieira, 2016). The choice of impact assessment methods was however something that the DG ENV later said would be tested in the PEF pilot and if necessary, changed or improved (Galatola & Pant, 2014). Compared to the initial set of impact categories found in the PEF guide some models have already been updated or changed (EC, 2013).

Positive aspects are that the development process regarding the impact categories has been relatively transparent and that is has also involved a large number of stakeholders and experts. Some characterization factors are also spatially differentiated, which may increase the representativeness since the vulnerability towards especially acidification and eutrophication can vary significantly between different regions ad countries (Vieira, 2016). Due to the increased complexity of using regionalized characterization factors however, cost for companies may increase (Finkbeiner, 2014).

Adding these new ways of estimating the potential impact of activities may either have good or bad implications for Nouryon depending on how they are based and structured in detail. There may also be variations between different PEFCRs in how they are applied. One aspect that is of special relevance for Nouryon is how biogenic carbon is accounted for in the climate change impact category. The company wants that the efforts of using biobased raw materials in chemical products are accounted for. Both PEF and IES use the same characterization model, and both distinguish between biogenic and fossil carbon dioxide emissions. In PEF the characterization factor is set to zero (Schryver, Galatola, Schau, Benini, & Pant, 2016 as cited in Fazio, Castellani, Sala, Schau, Secchi, Zampori & Diaconu, 2018). Supposedly this is a good thing in the eyes of Nouryon.

8.2.5 Review and reporting

As for Nouryon the EPD reporting, and review process is familiar since it has been carried out previously. For PEF the question remains how easily this is carried out. Both the PEF guide and the GPI rules are compliant with the ISO 14040 series. The PEF reporting format may vary between product categories but do in general include a summary, general information, goal and scope, LCI, impact assessment results, interpretation of results and annexes (EC, 2018). The required parts of an EPD include cover page, programme- and product information, content declaration, environmental performance, additional information and references (Del Borghi et al., 2020).

When it comes to the review and verification processes, PEF requires a critical review for any study that is intended to be communicated either internally or externally. The type of review will also differ based upon what type of communication is intended, from only the need of one individual reviewer or an entire panel. Specific reviewer qualification criteria in the form of a scoring system are provided by the PEF guide. For EPDs, the organizations carrying out the study is responsible for that the data is verified either externally or internally and only in terms B2C communication a third-party review is required. This is done by accredited certification bodies or approved individual verifiers, which in turn are approved by the programme operator or other accreditation bodies (Del Borghi et al., 2020).

One aspect is also the validity time. An EPD is normally valid for 5 years. This if there is no worsening of any impact category by more than 10% of the impact stated in the EPD during that time period. Results are still allowed to be shared after the 5-year period but may not be used for marketing purposes (EPD Intl., n.d.). For PEF, each PEFCR determines the maximum validity time, but the overall maximum is three years. Similar to EPD, it must be updated if one impact category is worsened by more than 10%, but also if the total aggregated score is worsened by more than 5%. This is assessed annually through follow-ups involving the verification body (EC, 2018). Nouryon, does not have any internal principles regarding the validity of eco-footprints and the more open requirements of EPD could be a good guidance if setting any such principles.

8.3 Policy relevance

In terms of policy relevancy there are some examples where EPD is present in legislation. In the Netherlands, the so-called *Dutch Building Decree* demands construction companies to attach an environmental performance report (similar to an EPD) as part of the permit process regarding construction of most residential and office buildings (Scholten & van Ewijk, 2013). In Sweden, the government intends to implement similar regulative requirements, so called *Climate declarations of buildings,* which will enter into force in January 2022 (Finansdepartementet, 2019). In this process *The National Board of Housing, Building and Planning* has been commissioned to put forth a reference database with relevant LCI data for the construction of buildings, a climate declaration database and guidance documents for producing such declarations (Boverket, 2020). As for Nouryon, being familiar with the EPD method in general helps in the processes of adapting to individual national EPD standards for specific sectors. However, having to adapt to several different national EPD schemes and regulations, including differences in LCA method and data gathering from different national reference databases, in order to exist on several markets may inflict additional cost.

On the contrary, using PEF in EU policy could be a way of avoiding these issues. PEF was early on presented as suitable for EU policy where existing LCA standards is either insufficient or incompatible (Galatola & Pant, 2014), but since they were also describing as voluntary, the role of PEF as a legislative tool was questioned (Finkbeiner, 2014). However, in March 2020, as a part of the Green Deal, the Circular Economy Action Plan (CEAP) was released, which referred explicitly to PEF in three different legislative initiatives and actions (Spak, 2021):

Design of sustainable products

addresses the issues related to short lifetimes of products. The commission wants to introduce several so-called sustainability principles that include improving durability of products, increased use of recycled content, reduced carbon and environmental footprints among others. These principles will act as overarching guidelines in order not to conflict with any other policy instruments regulating products. However, some legislation will be reviewed, e.g., the Ecodesign directive, to which criteria and rules from newer developed frameworks including PEF, may be implemented (EC, 2020a).

Empowering consumers and public buyers

Aims to increase the participation of consumers in the circular economy by targeting green claims of products. The CEAP suggests that EU consumer law should be revised in order to ensure that consumers are provided with credible and relevant information that involves the full life cycle of products. Minimum requirements for sustainability labels logos and information tools may be set as well as implementing the use of PEF. Initial tests will include the EU Ecolabel (EC, 2020a). In addition, the Empowering consumers and public buyers action also suggests minimum criteria for green public procurement to be set using OEF as a compulsory reporting and monitoring tool (Spak, 2021).

New Battery regulation

In terms of the new battery legislation focusing on sustainability and transparency requirements for batteries, the CEAP also suggest the use of carbon footprints of battery manufacturing to be considered (EC, 2020a). This involves the use of the specific environmental footprint rules set for batteries (Spak, 2021). The way PEF is implemented is exemplified in the annex to the battery regulation where it is specified which impact category from the Batteries PEFCR is to be used and how the results are to be presented (EC, 2020b). This is a likely format for PEF implementation in other legislative documents as well (Spak, 2021).

Looking at the progress of these initiatives the Design of sustainable products initiative is having a consultation round between march and June 2021. The legislative proposal is planned to be presented in the end quarter of 2021. The empowering consumers and public buyers (green claims) initiative had its consultation round between August and December 2020 and a legislative proposal is planned in the second quarter of 2021. The new battery legislation was proposed in December 2020 and is planned to entry in force in January 2022 if the negotiations finish as planned in October 2021. The PEF is mentioned in three *delegated acts*: *Carbon reporting, performance classes* and *maximum levels* all of which have different dates for proposal and entry in to force that stretches between 2023 and 2027 (Spak, 2021).

As for Nouryon taking interest in the PEF development increases the chance of being ready for any policy changes of relevancy. The impression is also that the European Commission is open for stakeholder participation in the development of such policies and the PEFCRs in general, making it possible for companies to influence the outcome. However, with all the uncertainties remaining, especially for products outside the current policy proposals and the PEFCRs, it is uncertain how much such effort will provide in return.

8.4 Maturity

Lastly, an important aspect comparing EPD, and PEF is the maturity level. Strengths of the EPD system is that it is already established and well known. Even though it is voluntary for most companies and sectors there is a growing demand and use in many countries (Ibáñez-Foréz et al. 2016), something that is also experienced by Nouryon. PEF which is still in its early development phase with only a handful of PEFCRs developed, has a long way to go in comparison. In time it may be successful in achieving its goal, be the dominant environmental footprint system in Europe, but the question also remains what role it will play outside EU borders. It has even been argued that PEF and OEF do not respect international LCA standards and therefore can create trade barriers if countries such as China or India does not want to comply with it (Finkbeiner, 2014).

Still, there is no reason to neglect PEF entirely. It has the potential of providing uniform communication standards and labels increasing the transparency and credibility regarding the communication for environmental data. Furthermore, by acting as a universal programme operator increased comparability between studies is possible. On a seminar held by the SLC, 25 respondents from different companies an organization interested in PEF answered questions on their current positions towards PEF. 40% said they had not taken a position while 60% had either already started investigating the implications of PEF or were at least considering it (SLC, 2021). To conclude it is recommended to keep an eye on the development of both systems, in order to be prepared for that customer are suddenly asking for PEF data as well as EPD data.

8.5 Conclusion SWOT analysis

The summarized results are found in table 8.3. In general, the aspects of EPD are clearer than of PEF, i.e., they are expressed more in terms of strengths and weaknesses while for PEF, opportunities and threats. EPD is the more mature and recognized framework which is applied worldwide. It is therefore highly recommended by Nouryon to continue to acknowledge this framework and perhaps take it into consideration in its eco-footprint even more than before. Especially since EPD seems to be more and more implemented in national policy as well. However, even though PEF is the outsider it is important to still keep an eye on its development, and also as aforementioned, take the opportunity to get involved in the development of e.g., relevant PEFCRs. The ambition of PEF is high as well as its potential. In time, it may therefore be an equally important factor on the European market as EPD.

Table 8.3. Aggregated results of the SWOT analysis comparing PEF and EPD based on the prerequisites of Nouryon.

Aspect	PEF	EPD
Intended use	O. Includes the LCA applications used by the company today. O. Little limitations for future expanded applications. T. Actual applications of PEF are not yet clear, especially for products that have not yet been addressed in any PEFCRs. T. Too extensive as a communication format	S. Already used by Nouryon today. W. Too extensive as a communication format
<u>LCA method</u>		
Scope	T. More complex functional unit. T. Applying both an attributional and consequential approach may add complexity. O. Applying both an attributional and consequential approach may open new LCA related applications. O. Foreground and background processes matches the use of scope 1-3 quite well. T. Scope 2 has no clear equivalent.	S. Simpler functional unit. S. LCA studies are generally attributional which fits the EPD method well. S. Scope 1 and 3 matches the downstream and core processes of EPD quite well. S. Scope 2 has no clear equivalent.
LCI	T. Different terminology may lead to confusion. O. Guidance in data collection and management may boost efficiency and comparability. T. Cut-off may only be allowed for specific PEFCRs. O. Allows for system expansion. O. Provided formulas for allocation may increase simplicity. O. Provided formulas for allocation may not be of relevance.	S. Same terminology. S. Cut-off is allowed. W. Does not allow systems expansion.
Data quality	T. Quality assessment of both specific and generic data may increase time effort and costs. O. More flexible use of specific and generic data for primary (foreground) processes. O. Use of limited data sources may increase simplicity. T. Use of limited data sources may increase the risk of missing out important environmental information.	S. Only requires an assessment of generic data. W. Less flexible use of specific and generic data for primary (core) processes. S. Generic data from any source increases flexibility. T. Generic data from any source may increase complexity.

Table 8.3 (Continued)

LCIA	S. Compatible with GaBi. T. Controversial set of impact categories. O. Changes may still occur in future PEFCRs. S. Transparent and inclusive development process. O. Spatial differentiation may increase representability. T. Spatial differentiation may increase complexity. O. Biogenic carbon differentiation.	S. Compatible with Gabi. S. Acknowledged set of impact categories S. Biogenic carbon differentiation.
Review and reporting	T. Unfamiliar process and format. W. Excessive verification process. W. More strict validation requirements	S. Familiar process and format. W. Excessive verification process. S. Less strict validation requirements
Policy relevance	O. Avoids the issues of having every country managing their own EPD standards and reference databases. O. Possible for companies to influence the outcome. T. Uncertainties remaining, especially for products outside the current policy proposals and the PEFCRs,	S. Easy adaptation to upcoming national policies. T. Countries having and managing their own policies instead of one common framework.
Maturity	W. Not established and not well known. W. No current demand. O. No demand yet. O. Single type of label easier to understand and compare. T. Uncertainty about use outside the EU T. Uncertainty about other PEFCRs	S. Established on the market and well known. S. Growing use and demand. S. Exists outside the EU. T. Interest may decrease with the implementation of EPD. W. Many different programmes and different labels

9 Suggested improvements

Eco-footprints are today used as a flexible way of communicating environmental performance data. It is not a fixed format using not just one specific LCA method and can instead be altered based on the demands and requests from customers. This is a good thing, both for not risking leaving out unnecessary confidential information but also when taken in into account different environmental standards for market communication such as PEF and EPD, which are similar in some ways but also different and thus require different LCA approaches. Since the development of these standards and the overall demand from customers is unclear, being able to adapt is important. Important still, when working with such a flexible format is to at least have a common framework so that there is a common ground on how to structure the LCA practice. This section will initiate a discussion for building such a framework.

9.1 Work process

Simply by illustrating the current work process as done in section 7.2. a general framework is provided for how information is transported between different parties. The overall structure is also a good starting point for decisions making, and a guide for working with eco-footprints. There are however some things that may be improved if looking in the greater detail.

Starting with the initial request form customers to the market and sales department. Instead of simply passing the contact information to on to the sustainability manager, there could be a routine for specifying the request a bit more. E.g., what type of environmental data is requested, any data quality requirements and what format. With that information a customer evaluation can be done in order to determine if the request is valid or not already at the initial point.

Second is the aspect of when eco-footprint data is considered out of date. This is primarily up to the customer to decide and but if considering the requirements of standards for environmental market communication, there could at least be some routines of updating the data if there has been some known major improvements or changes to the production itself. During interviews the current practice was questioned by process engineers that very much would appreciate that the continual environmental improvements they contribute to the production at site level would be acknowledged in the environmental performance data of products. Instead of updates being sporadically carried out with up to ten years apart, it is instead done on a more regular basis. One option is to have the requirements of EPD as a reference, that a revision should be done every 5 years or if a change is done that alters the environmental impact with more than 10%. Another option is to have more closer insight in the activities on-site. A closer collaboration between sustainability managers and the on-site product experts, environmental specialist and process engineers, or at least the R&D departments which also have good insight in what major improvements that are carried out.

Third, concerning the decisions required when a new eco-footprint or an update is needed. Today there is no clear LCA commissioner role. I.e., no formal decision-making body in terms of LCAs Furthermore, there is no clear terms on what is desired from the LCA, what budget constraints there are, no clear procedure on how the decision-making is carried out or who will do it etc. E.g., if the LCA should be carried out by the business sustainability manager or the central sustainability team, and how much time and resources that should be put on it. It has been requested that routines are developed that makes the criteria and decision making more straight forward. Such routines would also very much be benefited with a closer collaboration with the market and sales departments, which also have the best information on how important the customer is and how much effort is worth putting on satisfying their needs.

9.2 Data management

Concerning data management and the issues regarding size and structure of the Gabi database, possible things to consider may be first, to make versions of the master database, one including older things that may no longer be of relevance and one *light* version with only the most relevant and up-to-date data. This could both make the database smaller in size and easier to work with but also more comprehensible when searching for datasets etc. Another thing possible to apply is the *Quality Assurance (QA) status* in the GaBi database manager. There are four different QA statuses: (1) *draft*; (2) *Ready for QA*; (3) *Needs revision* and (4) *Quality assured,* and different roles (LCA experts, Project managers and administrators) have different possibilities to switch between the different statuses (PE International AG, 2012). By starting to apply the QA status on objects in GaBi, especially differentiating between "draft", "ready for QA" and "Needs revision", it may become easier to distinguish between objects of high and low relevancy and quality.

Second, is to have a dialogue regarding the naming and structure of folders and objects. Here it did not seem to be a consensus, or any straightforward approach so further work may be needed in order to come up with good solutions useful for everyone. Things to consider is to how make the structure: (1) less dependent on organization structure and perhaps more on product lines which are more *robust* and constant over time; and (2) more homogenized between business (primarily between performance formulations and technology solutions).

Third, concerning the nomenclature. The fact that there are information, guides and principles already formulated are great. However, there may be need for more clear routines on how to access the guides and who is responsible for them. Nouryon is already applying a practice for routines and guidance documents according to the internal *Lean* management system, called *standardized work sheets* (SWS). Something that may be useful to apply to shared LCA documentation as well.

9.3 LCA method

Here follows suggestions on how to carry out the LCA method when producing an eco-footprint.

9.3.1 Goal and scope definition

Even if the eco-footprint is not intended to pass any review or verification, still it is important to follow the structure provided by ISO 14040. This in order to make it more credible and transparent, but also easier to understand the results. All parts of the goal and scope are not necessary to include in the final communicated eco-footprint, but it is important for internal purposes to have it stated before initiating a LCA process. Ideally the goal and scope are defined in such a way that the eco-footprint (LCA study) could be redone from scratch, without any need of making additional assumptions of how it was carried out. The goal and scope can be formulated on a document but also implemented in when creating processes in GaBi, as will be described in the following section. The goal of the eco-footprint should also be stated so that the intended outcome matches the demand specification of the customer.

Functional unit

The default by using 1 metric tonne of product as functional unit, very much fulfills the need of ISO 14040 and EPD. However, in order to be PEF compliant alterations may be necessary, but guidance should be provided in PEFCRs on how to proceed in such cases.

Flowchart

A flowchart describing the product system, including its processes, flows and boundaries should be included. Possibly including a subdivision distinguishing the foreground system and the background system.

System boundary

The way cradle-to-gate is used in general, aligns with the ways of ISO 14040, EPD and PEF. Still, it needs to be clearly defined.

Natural boundary

Sometime boundaries between the natural and technological environment are obvious, but there are cases where they should be clearly stated. E.g., end-of-life treatment such as landfilling or use of biomass as fuel or raw material.

Geographical boundary

It is very important to state where the life cycle takes place since it affects the choice of regionalized data. Furthermore, PEF will also use regionalized impact categories. The way environmental performance data sometimes is extrapolated to other similar sites is questionable. It may be sufficient for informal purposes but should in such cases be stated.

Cut-off criteria

All things such as personnel, machinery etc. may not be defined but, it is important to state the non-obvious ones such as e.g., chemical additives. Uncertainties regard the PEF method which in principle does not allow cut-off methods, but exceptions may be present in specific PEFCRs.

Allocation

The allocation methods chosen should be stated and motivated.

Time horizon

Similar to the natural boundaries it is particularly important for waste management and end-of-life treatment of by-products. If any other time frames used for LCIA models than the most common ones are used (e.g., GWP1000 instead of GWP100) this should also be stated and motivated. Furthermore, what timeframe the data covers and how long it can be assumed to be valid. This will help in the process of determining if an old eco-footprint still is valid or not. If the eco-footprint is to be carried out with either EPD or PEF a validity time is required.

Data quality requirements

In addition to above mentioned criteria important things are completeness, representativeness, consistency, precision and reproducibility of the data. In principle, data should be as specific and current as possible. If there are exceptions made, this should be motivated. One example is specific data for a reactor that may vary depending on how old the catalyst is. If the catalyst is changed every 1.5 years, it is perhaps better to use the mean over 3 years rather than for just one year.

Assumptions and limitations

Any other major assumptions or limitations may be stated., e.g., considering data gaps or use of fuel mixes etc.

9.3.2 LCI

Here follows a discussion regarding data collection and data recalculation.

9.3.2.1 Data collection

In terms of sources of primary data, there are bill of materials, environmental reports and MES software, supported by close communication with product specialist, process engineers and environmental specialist, while secondary data is gathered from reference databases and suppliers. What reference database used may vary if the eco-footprint is carried out according to a specific environmental standard or not.

Data collection should cover numerical, descriptive and qualitative data. The more information about the data itself the easier it is to apply it in the modelling and the higher the quality of the LCA itself. It makes it more comprehensible, more transparent and more credible. This is however something that could be rather difficult to achieve in reality, something that has also been shown in this study. One approach could be to have a common data collection template. This could make the data collection process clearer and more transparent, both for the data provider and the one asking for the data. It could also make the data collection more straight-forward and thereby also more efficient.

Appendix III: Data collection template includes a suggested data collection template. It is based on the possibilities of adding numerical, descriptive and qualitative data in GaBi when creating processes. Following this template would therefore make it easier to include all relevant data for both processes and flows at one place. Things to include are e.g., additional information in order to understand the process and flows, details about the data collection, modelling etc., assumptions and administrative information. All information may not always be relevant for every process that is created. However, it is strongly recommended to include as much information as possible. The time spent will be returned when the final eco-footprint report is created, when others use the same data and when it must be updated later.

9.3.2.2 Data recalculation and allocation

As described in section 7.4.2, allocation problems are very much present in the chemical industry due to the large complex network of processes and creating a standardized allocation method that in detail explains what allocation methods to use, have been placed outside the scope of this work. However here follows suggestions on how to proceed in general terms.

Before applying any allocation methods all activities relevant for the product system must be identified (Baumann & Tillman, 2004). That means that all activities that share the same flows of raw materials, products and emissions should be identified and for a chemical manufacturing site this could imply that most of an entire site is included in the scope. Cut off-criteria may be used here in order to keep the complexity level manageable. However, every assumption made should be stated and motivated clearly.

In accordance with ISO 14040, allocation should preferably be avoided using e.g., system expansion. If carried out according to a specific standard, the special requirements of such should also apply. This implies that for non-EPD eco-footprints, system expansion and crediting methods can be used for steam. Otherwise, methods based on e.g. The polluter pays principle can be applied. For other circumstances allocation methods should be carried out based on physical relationships (i.e., mass or energy content) or lastly economic value. Important is the physical-causal relationship and the 100%.

9.3.3 LCIA

Suggested LCIA methods to use are the default indicators in the International EPD programme, i.e., the ones displayed in table 8.2. This would imply that CML 2001 is kept for most impact categories with the exception of photochemical ozone creation potential which instead use the ReCiPe model. Water scarcity footprint is also added using the AWARE method. What is also added is the effect on land use and land use change. What is missing is the ozone depletion potential which is only regarded as recommended in the default EPD indicators (IES, 2018) and is not included neither in the PCRs for organic nor inorganic chemicals (EPD International, 2019, 2020). It is therefore only when considered relevant for the product to include impact categories for ozone depletion.

9.4 Suggested eco-footprint format

A suggested template for future eco-footprints can be found in Appendix IV: Eco-footprint template. It is based on the current eco-footprint format (section 7.4) bud adds components from EPDs carried out by Nouryon for hydrogen peroxide (Nouryon, 2019b) and Sodium chlorate (Nouryon, 2018) as well as the PCRs for basic organic (EPD International, 2019) and inorganic chemicals (EPD International, 2020). In short, it introduces more details about the scope, how the LCA has been carried out as well as some additional information. What is not included is a content information section, describing the materials used for the product and their potential hazardous properties. Such information may be sensitive and only be induced when doing a full EPD. Neither is the environmental impact distinguished between upstream, core and downstream processes. This also due to confidential reasons. What is included in the current eco-footprint is also a list of LCI results in terms of emissions to water and air. This not included in the EPD format as is therefore not necessary in in the ecofootprint. Removing it adds simplicity but may be less helpful for downstream users that are more interested in the LCI instead of LCIA data.

10 Discussion

Here follows an ending discussion of the outcome and limitations of the work and how it relates to some examples of similar scientific literature.

10.1 The outcome

The aim of this work was to provide insights on how LCA could be better practiced at a larger international organization, by proposing a standardized Nouryon eco-footprint methodology for Nouryon. The approach taken was to first identify potential weaknesses regarding the current LCA organization and method concerning eco-footprints, based on standards for environmental market communication. This involved an organization mapping as well as a literature review and evaluation and thereafter suggested improvements to the work surrounding eco-footprints.

Looking at the expected outcome formulated in the initial phase of the project, it included a flow diagram describing the production and communication of eco-footprints, a sustainability organization chart that described which people that holds which responsibilities and competence, suggestions on how to structure and manage datasets and finally a proposed way of defining goal and scopes of LCAs, where aspects of external environmental standards have been acknowledged. Most of these things have been considered, e.g., the actor identification and the work process descriptions have been ways to describe the actors, their responsibilities and communication pathways and in chapter 9 some suggested improvement to the Nouryon eco-footprint methodology are presented. These include discussions on how to define goal and scope, how to manage data etc.

10.2 Limitations

The Nouryon eco-footprint methodology proposed remains a framework with more brief descriptions and discussions on how to do things and why, rather than detailed instructions and there are a few reasons why this is the case. First, the time limitations in combination with the rather open scope and approach of the project. The intention was never to prove a certain thesis or theory but to describe how the company is working with LCA. The possibilities on what to include have therefore almost seemed unlimited and boundaries drawn and comprises have been necessary along the way. Furthermore, LCA in the context of the chemical industry in general is highly complex, e.g., regarding allocation procedures, and this work alone cannot provide enough foundation to propose a universal procedure in detail. Instead, it acknowledges the complexity and by that encourage further research and dialogue.

Furthermore, the geographical aspects combined with the circumstances surrounding Covid-19 have very much influenced the possibilities of getting insights in the LCA organization. Involved actors such as the sustainability team are spread across Europe and the United States and meetings have only been possible using digital communication tools such as email and video calls. The exception has been the supervisor of the project, representing the business sustainability manager at Performance Formulations, which is the only one who has been able to participate in person, and therefore also have been the most important source of information regarding the LCA organization. The outcome of this is that focus has been put more on the role of sustainability manager, e.g., in the work process descriptions and less from the view of the other members of the sustainability team.

This is an important limitation of this work to acknowledge getting a chance to have a closer contact with the rest of the actors may have broaden the perspective and added more value to the final outcome. Still, the role of the business sustainability manager has proven to be important for the carrying out of eco-footprints and acting as a focal point for communication and managing environmental performance data. Therefore, by describing the role of the sustainability manager in more detail this has provided some insights in LCA practice and therefore also contributed to the overall aim.

Another thing that has been altered during the project is the focus on standards for environmental market communication. The information available regarding PEF was much scarcer than first anticipated, and the overall knowledge about it in the organization turned out to be limited. Therefore, more time was spent on the literature review describing PEF and EPD, their differences and what implications they may have for Nouryon. This process was time consuming, and it also relied on a webinar held by the SLC in the later stages of the project. Hence, postponing some parts of the work, especially the evaluation and SWOT analysis of PEF and EPD.

Lastly, data collection in terms of the two planned case-studies was also something that was limited. During the project, emails and requests were sometimes not answered and it was difficult to have a dialogue about data, leading to that the work was haltered. If these case studies had been carried out at a full extent it is also possible that a deeper understanding about the LCA method could have been obtained. Still, this process was valuable in terms of realizing that data collection and communication in general may be one of the most important aspects of the work surrounding eco-footprints. Partly, due to the importance of asking the right questions, in order to get the right environmental data, but also since the risk of it being a bottleneck. Making communication pathways more straight forward and reliant can thereby be a recommended target. Especially since communication is likely to be even more digitalized and less personal in the future.

10.3 In relation to scientific literature

As mentioned in the introduction and background sections of this report, there seems to be a knowledge gap concerning how to manage the work surrounding LCA outside simply performing the calculations (Rex & Baumann, 2004). This work may thereby contribute to filling that gap, by providing some insights on how LCA is practiced at Nouryon: what areas of improvements there are and suggested approaches to these. Still, a few similar studies have been made and it is interesting to see how the results compare. When looking at how LCA was practiced in the Swedish forest industry, Rex & Baumann (2004) identified two particular challenges: first, how to implement LCA so that it is integrated in way that it can survive reorganizations and personals shifts? and how to broaden the scope so it can be used outside the environmental departments? (Rex & Baumann, 2004).

Both these challenges are of high relevance for Nouryon, since the results of this work have shown that there are issues needed to be addressed in order to make the work surrounding LCA and eco-footprints more robust and resilient to organizational changes. In addition, even if the history of conducting LCAs at Nouryon traces back a relative long time, LCA is still only of the concern for a small group, making it more fragile and limited in applications. By documenting and acknowledging the work however, which has been done here, the chances that these issues can be addressed may be increased since it becomes more visible and clearer for the involved actors.

Studies have also pointed out the management and collection data of data to be of special concern (Svending, 2003; Baumann & Tillmann, 2004) and this was very much confirmed in this study. Work surrounding LCA would therefore benefit from having further insights on why this is the case, and potential ways to approach it. For Nouryon, the template for data collection suggested in this report could act as good start. However, there may be additional efforts that can be made elsewhere, e.g., to increase direct access to primary sources of information in order to avoid personal communication as much as possible. There are many digital centralized systems and databases already in use for managing primary data regarding production or environmental flows. If these could be accessed directly instead of using a third-party, many barriers related to data collection could potentially be avoided.

11 Conclusion

Insights on how LCA is practiced at a larger international company have been provided by documenting parts of work surrounding eco-footprints at Nouryon, identifying areas of improvement, specifically the work process, data management, data collection, allocation and communication format; and lastly suggesting possible approaches to these. This was done using a combination of a literature review covering LCA and standards for environmental market communication; a stakeholder dialogue; and lastly, getting familiar with the LCA software and database through some small cases.

First regarding the work process in general, the mapping done here serves as a basis for further dialogue and making the Nouryon eco-footprint methodology more transparent, efficient and straight-forward for the involved actors. Second, in terms of data management, possible ways of approaching issues related to database size and inconsistent naming and structure can be to improve the routines surrounding instructions documentation using already existing management systems in the company, consider folder structure based on production rather than organization levels and using two versions of the database. Third, in terms of data collection, a template was presented to minimize problems related to incomplete data and time consumption. Fourth, allocation was identified as a crucial area that may need to be further investigated. However, a first set of general principles for allocation was suggested as a start for discussion. Lastly a suggested template for a communication format was presented.

Limitations have been present due to geographical and time related reasons and there are several areas that may be explored further. Still, the outcome of this work may act as a basis for further, more detailed measures for standardizing the internal work surrounding eco-footprints at Nouryon. Furthermore, by providing detailed insights on how LCA is practiced in a larger organization it may also contribute to the deeper understanding of how LCA is best practiced in general, and thereby be of use of the LCA community as a whole.

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Appendix I: Methods for recycling

Table A.2. displays several alternative allocation methods for recycling.

Table A.1. Alternative allocation methods in open-loop recycling rule (Baumann & Tillman, 2004).

Cut-off	Loads are only assigned to products which they are directly connected to. E.g., raw materials are only accounted for the loads generated from the raw material extraction and not any downstream processes, such as recycling, use or waste treatment. This is the simplest approach since it does not require any data or knowledge of processes outside the life cycle of the studied product.
In relation to loss of quality	The total life cycle load is divided between different products based on the relative loss of quality between each product. A product with higher relative quality will therefore be appointed with a higher load. This requires great knowledge about the full life cycle but is still difficult to do and often economic value is the only possible approach.
All raw material acquisition generate waste	Here it is argued that raw-material extraction is the reason for the generation of waste in the first place and therefore that the raw materials should be appointed with the environmental load from waste treatment in addition to the raw-material extraction. In general, this promotes use of more recycled materials rather than virgin materials.
Materials lost as waste must be replaced	On the contrary, one can also argue that any generated waste needs to be replaced by virgin materials and therefore that it is the end-product that is disposed that should be accounted for the loads from both waste treatment but also raw material extraction. This in turn promotes the production of recyclable product instead of use of recycled materials.
50/50	Assumes that recycled materials replace virgin materials and other recycled materials by 50%. Raw materials and end-products share the load of raw-material extraction and waste treatment. While intermediate products are accounted for half of the materials needed and half of the recycled products. This method is suitable when you have little knowledge about external life cycles but can assume that quality is not remained through each recycling step.
Closed loop approximation	The total load is evenly distributed between all product along the product chain. It is assumed that the quality is preserved through every recycling step and that recycled materials replace virgin materials without affecting recycling of other materials. This holds for many metals which does not lose much quality when reprocessed and were sorting and recycling is done carefully.

Furthermore, there is the concept of *recycling rate* which may refer to either (in %; Baumann & Tillman, 2004):

- *Collection rate (C)*, the share of generated waste that is collected for recycling.
- *Recycling rate after losses (R)*, the share of the collected waste that is recycled.

- *Return rate (RT)*, the share of recycled materials used for a new product. In case of closed-loop recycling, the recycling rate of losses equals the return rate (see R=RT (Eq. 1), but this only occurs in rare occasions.

$$R = RT \quad \text{(Eq. 1)}$$

Another common way of expressing recycling is the *trip number (N)*, which refers to the number of times a product or material can be recycled. In closed loop recycling the relationship between the trip number and the recycling rate is expressed as C = 1- 1/N (Eq. 2 (Baumann & Tillman, 2004).

$$C = 1 - 1/N \quad \text{(Eq. 2)}$$

Which in turn shows that the higher the trip number the higher recycling rate. The recycling rate is also less sensitive to changes in trip number the higher the trip number is, something that is important to recognise when making assumptions of the trip number.

Appendix II: LCIA methods

Table A.1. Some examples of LCIA methods to use in GaBi (Sphera, n.d.).

AADP	*Anthropogenic stock extended abiotic depletion potential.* In addition to traditional ADP, it takes into consideration resources present in products and landfills.
CML 2001	Restricts quantitative modelling to early stages in the cause effect chain in order to minimize uncertainties. Results are presented in mid-point categories.
EDIP 2003	Focuses on the later stages of the cause-effect chain in order to address the environmental relevance of the results.
Impact 2002+	Combines 14 midpoint categories into 4 summarized damage categories.
Environmental Footprint (EF)/ILCD recommendation	Relates to the PEF/OEF initiatives. Version EF 2.0 includes characterization factors for PEFCRs/OEFSRs developed in the PEF pilot phase, while EF 3.0 targets any other PEF/OEF study.
ReCIPe	A merge between the midpoint categories in CML and the endpoint indicators of ECO-indicator. All indicators exist in three versions: (1) Short-term interest and optimism towards human adaptation (Individualist). Uses short term time frames for indicators such as e.g., GWP20; (2) Medium timeframe perspective (Hierarchist), based on common policy principles, such as e.g., GWP100; (3) Long timeframe, based on precautionary principles (Egalitarian), e.g., GWP1000. Users can choose between 18 midpoint indicators and 3 endpoint indicators.
TRACI	The *Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI)* was developed by the U.S Environmental protection agency with the aim of enabling Impact assessment for sustainability, LCA, industrial ecology, process design and pollution prevention Indicators are characterized on mid-point level. Human impacts are specifically adapted to US conditions.
UBP 2013	The Ecological scarcity method which uses the so-called distance-to-target principle. Eco-factors are expresses as eco-point per unit of pollutant or resource extraction, which in turn are implemented in 18 different environmental impact categories.
USETox	Developed by the UNEP/SETAC Life cycle initiative. Uses four different scales: indoor, urban, continental and global, which in turn utilizes up to five different compartments: air, agricultural soil, natural soil, freshwater, and sea water.
ECO-Indicator 99	A damage-oriented methodology with three weighted endpoint categories: Human health, Ecosystem Quality and Resources.
ISO 14067	ISO standard for the quantification of carbon footprints. Uses the AR5 characterization factors for GWP100 and the impact is split between four subcategories: fossil, biotic, aviation and land use.
AWaRe and WSI	*Available water remaining (AWaRe)* and *water scarcity index (WSI)* display water consumption, based on country specific characterization factors. Resulting units for WSI is *Water Deprivation* in cubic meters and for AWaRe *User Deprivation Potential (UDP)* in cubic meters.

Appendix III: Data collection template

The following information has been added to an excel-sheet. (see figures A1 and A2).

	A	B
1	*Process information*	
2	Name of process	
3	Country	
4	Source	
5	Type of process	
6	*Process documentation*	
7	Key information	
8	Quantitative refrence	
9	Time representativeness	
10	Geography	
11	Technological representativeness	
12	Mathematical model	
13	*Modeling and validation*	
14	LCI method and allocation	
15	Data sources and handling	
16	Completeness	
17	Validation	
18	*Administraive information*	
19	Commisioner and goal	
20	Data set generator/modeler	
21	Data entry by	
22	Publication and ownership	
23		

Figure A1. Data collection template: Process information.

	A	B	C	D	E
1	**Flow information**	**Flow 1**	**Flow 2**	**Flow 3**	**Flow 4**
2	Name of flow				
3	Input/output				
4	Type of flow				
5	Relevant parameters				
6	Amount and unit				
7	Standard deviation				
8	Origin				
9	Comments				
10	Price/cost				

Figure A2. Data collection template: Flow information.

Process information

Name of process

Country

Source

Type of process:

Unit process single operation (u-so), e.g., chemical reactors; u-bb, for combined processes but where data cannot be separated, e.g., a chemical plant; agg, full cradle-to-gate aggregated data, e.g., raw material extraction and production from suppliers; p-agg, where parts of the aggregated data need modelling; and aps, which can be used for crediting and system expansion.

Flow information

Name of flow

Input or output

Type of flow:

Raw-material, product, bi-product, waste, emission to soil, water or air. Will help find the correct flow in GaBi but also determine if it is a tracked, waste or elementary flow.

Relevant parameters

Amount and unit

Standard deviation

Origin

Measured, Calculated, estimated, or literature.

Comments

Relevant information in order to understand the context of the flow.

Price/cost

Process documentation

Key information

Here one can specify the production route, further quantitative specifications such as energy content, density etc, synonyms for the process or product produced (e.g., Different chemical names) and complementing processes that are linked. *General comments* may include how the data was collected and which contacts that were involved for what data. Preferably, the roles and businesses/companies/locations are stated for which data instead of just names (e.g., Environmental specialist, Site Stenungsund). Both due to GDPR reasons but also that the role is more useful than the name if the process is going to be updated some years later and the contact person has changed position and is replaced by another, who still has the same role. More detailed data collection detail may be included in the later section *Data sources and handling*.

Quantitative reference:

can be either a reference flow, functional unit, production period or other parameter.

Time representativeness:

The reference year is the start year for which the data set is valid. An end year is also possible to fill in as well as a comment describing more specified dates and not just years.

Geography

Specification on where the process is located, if there is further information rather than the site level.

Technological representativeness

Description of the process technology including the background system, i.e. The technological context of the process. Here one can also link with related processes already existing in the GaBi database. Here the technical purpose of the process can be described, i.e. The product application. One can also include pictogram and flow diagrams.

Mathematical model

Mathematical description of modelling used.

Modelling and validation

LCI method and allocation:

What type of LCA model (attributional, consequential etc.), what type of allocation methods that are used and any deviations from these.

Data sources and handling

Description of cut-oof criteria, principles of data selection, the percentage of data coverage. Annual supply and production volume, sampling procedure, time period of data collection, uncertainty adjustments and use advice for data set.

Completeness

a statement of the completeness of the product model but also elementary flows.

Validation and compliance declarations

Administrative information

Commissioner and goal

Commissioner of the data set, I.e. The one that has formerly requested the LCA to be carried out. The name of the project and the intended application.

Dataset generator /modeler

The name of the ones that has modelled using the dataset.

Data entry by

Name and additional information about the dataset.

Publication and ownership

The status of the project (working draft, final draft, finalized, published etc.) and additional information.

Appendix IV: Eco-footprint template

[Legal Entity]

[Department]

Eco-footprint

"[Product name]"

Published: [20XX-YY-ZZ]
Revision: [20XX-YY-ZZ]
Valid until: [20XX-YY-ZZ]

The underlying LCA has been prepared according with [e.g., ISO 14040, the international EPD systems, specific PCRs etc.]

About Nouryon

We are a global specialty chemicals leader. Industries worldwide rely on our essential chemistry in the manufacture of everyday products such as paper, plastics, building materials, food, pharmaceuticals, and personal care items. Building on our nearly 400-year history, the dedication of our 10 000 employees, and our shared commitment to business growth, strong financial performance, safety, sustainability, and innovation, we have established a world-class business and built strong partnerships with our customers. We operate in over 80 countries around the world and our portfolio of industry-leading brands includes Eka, Dissolvine, Trigonox and Berol.

Scope

Functional unit:	1 metric tonne
Data coverage:	[YYYY-YYYY]
System boundary:	cradle-to-gate
Product website:	[website] if applicable

[Additional information about assumptions, cut-off criteria, data quality, allocation and specific aspects regarding the production …

…]

The product

Production site:	[Name and location]
Production name:	[Product name]
Classification:	[e.g., CPC or CAS]

[Product description: applications, technical function and properties

…

Flowchart

Environmental performance

The figures displayed in the following tables include the environmental loads from all the processes in the life cycle of [Product name] cradle to factory gates, i.e., extraction of natural resources, raw material production, energy production and transportation. All figures are given for the functional unit 1 metric tonne of product.

Table 1. Environmental impacts.

Indicator		Impact assessment method	Unit	Amount
GWP 100	Fossil	CML 2001	Kg CO_2 eq	
	Biogenic			
	Land use and land transformation			
	Total			
Acidification potential (AP)		CML 2001	Kg CO_2 eq	
Eutrophication potential (EP)		CML 2001	Kg PO_4^{3-} eq.	
Photochemical ozone creation potential (POCP)		ReCiPe 2008	Kg C_2H_2 eq.	
Abiotic depletion potential (ADP)	Elements	CML 2001	Kg Sb eq.	
	Fossil fuels		MJ net calorific value	
Water scarcity footprint		AWARE	M^3 eq.	

Table 2. Resource use.

Parameter	Unit	Amount
Primary energy resources - Renewable		
Use as energy carrier	MJ, net calorific value	
Used as raw materials		
Total		
Primary energy resources - Non-renewable		
Use as energy carrier	MJ, net calorific value	
Energy resources [MJ]		
Total		
Secondary materials and fuels		
Secondary material	kg	
Renewable secondary fuels	MJ, net calorific value	
Non-renewable secondary fuels		
Water use		
Net use of fresh water*	m^3	

Table 3. Waste production and output flows.

Parameter	Unit	Amount
Wastes		
Hazardous waste disposed	kg	
Non-hazardous waste disposed	kg	
Radioactive waste disposed	kg	
Output flows (if applicable)		
Components for reuse	kg	
Material for recycling	kg	
Materials for energy recovery**	kg	
Exported energy, electricity	MJ	
Exported energy, thermal	MJ	

Additional information

Renewable feedstock:
[If biotic matter is used as feedstock, the type of crop and location of the growing crop should be specified. If there is no information this should be stated]

Potential environmental or health issues:

[e.g., biodegradability or biodiversity issues]

Websites:

[e.g., Safety data sheet (SDS) / Material safety data sheet (MSDS)]

Differences versus previous versions (if applicable)

[Changes made in the revision]

Glossary

Acidification	Chemical alternation of the environment, resulting hydrogen ions being produced more rapidly than they are dispersed or neutralized. Occurs mainly through fallout of sulphur and nitrogen compounds, from combustion processes. Acidification can be harmful to terrestrial and aquatic life.
Carbon footprint	Reflects the impact of an activity on climate change due to the greenhouse gases emitted. It is expressed as global warming potential.
Chemical Oxygen Demand (COD)	Used to indirectly measure the amount of organic compounds in water.
Eutrophication	Enrichment of bodies of water by nitrates and phosphates from organic material or the surface runoff. This increases the growth of aquatic plants and can produce algae blooms that deoxygenate water and smother other aquatic life.
Environmental Product Declaration (EPD)	Is defined as "quantified environmental data for a product with pre-set categories of parameters based on the ISO 14040 series of standards, but not excluding additional environmental information"
Global warming potential (GWP)	The index used to translate the level of emissions of various gases into a common measure to compare their contributions to the absorption by the atmosphere of infrared radiation.
Life Cycle Assessment (LCA)	A method for appraising and quantifying the total environmental impact of products or services over their entire life cycle (or parts of), based on the ISO 14040 series.
Ozone depletion potential (ODP)	The index used to translate the level of emissions of various substances into a common measure to compare their contributions to the breakdown of the ozone layer.
Photochemical ozone creation potential (POCP)	The index used to translate the level of emissions of various gases into a common measure to the change of ground-level ozone concentration.
Primary energy	The amount of energy needed directly from nature for the life cycle part from cradle to gate, it is expressed as the energy contained in the natural energy carrier (e.g., crude oil or biomass) before it has been converted to usable energy, such as fuel or electricity and applies to both non-renewable and renewable energy.

References

The underlying LCA (if published), environmental standards used, impact assessment methods, reference databases used etc.

AWARE	WULCA (n.d.). Home. Home - WULCA (wulca-waterlca.org)
CML 2001	Universitet Leiden (2016). CML-IA Characterization Factors. CML-IA Characterization Factors - Leiden University (universiteitleiden.nl)
ReCiPe 2008	tional Institute for Public Health and the Environment (2011). LCIA: the ReCiPe model. LCIA: the ReCiPe model | RIVM

Contact

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