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From Life Cycle Assessment (LCA) to Life Cycle Sustainability Assessment (LCSA), methodological issues and prospects for implementing circular business models[1]

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Abstract : The family of LCA ISO Standards is used to evaluate not only environmental, economic, and social impacts of a product throughout its life cycle but also those that can be assigned to baskets of goods, companies, households, countries, and the planet. If the Life Cycle Assessment (LCA) introduces basic steps (defining goal and scope of the assessment, inventory analysis, impact assessment, interpretation), the Social Life Cycle Assessment (SLCA) represents a valuable approach for accounting for social impacts associated with production and consumption along a supply chain, as well as to support decision makers in different contexts. Indeed, SLCA can be used to explore supply chains at different scale and industrial processes. The integration and the complementarity of the two approaches (LCA, SLCA) may trigger a few challenges: the variety of indicators, the assessment of positive and negative impacts, the interpretation of results, the involvement of stakeholders and the recognition of shared values, the decision making by different actors... But switching from LCA to SCLA is only the first step to engage the innovation process to a more sustainable pathway. The final goal consists of carrying the different actors of a supply chain to support the transition to Life Cycle Sustainability Assessment (LCSA). This global approach is useful to introduce the R-framework (from 4R to 10 R) to map Circular Economy strategies and to foresee how they influence the viability of value chains for the innovation cycle. Environmental, economic, and social impacts have to be considered regarding the three following scales (macro, meso and micro) to elicit generic interactions. At the micro level, the dashboard of sustainable indicators for all the partners of the supply chain highlights midpoints indicators and endpoints indicators. The gap between midpoint and endpoint indicators will challenge different pathways. Moreover, investigating the innovation process in the light of LCSA enables us to move from a CSR (Corporate Social Responsibility) - ideal type to a SDGs reporting. At the meso and macro level, the social acceptance of innovation plays a crucial role. The R-framework to support a circular economy may be relevant for challenging the equal balance of People, Profit, Planet, Peace and Partnerships
.

Key words: Circular economy, LCA, SLCA, LCSA, SDG

1. *Introduction, the slow ascension of LCA*

The Life Cycle Assessment (LCA) was invented in the USA in the late 1960s. Hunt and Franklin (1996) considered that the first formal analytical scheme, later becoming the LCA, was first conceived by Harry Teasley in 1969. Managing the packaging function of The Coca-Cola Company, he visualized a study that would attempt to quantify the energy,

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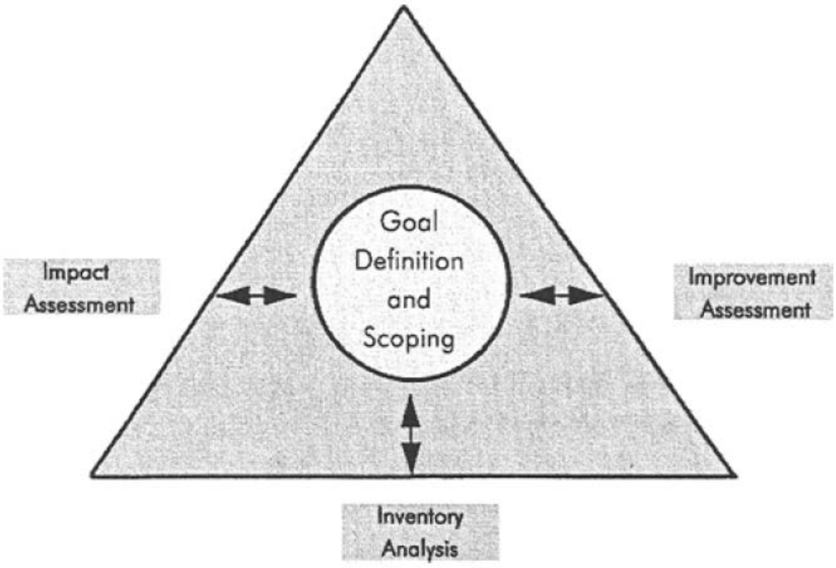
material, and environmental consequences of the entire life cycle of a package from the extraction of raw materials to disposal. At that time, the company was considering whether they should self-manufacture beverage cans, and they were looking at a number of issues relating to package manufactures and the possibility of using a plastic bottle. One of the innovative ideas from Teasley was the inclusion of energy in the natural resource category (four years before the oil crisis of 1973-1974). Economic growth was based on the assumption of cheap energy and high consumption of fossil fuels. This energy was expected to account for a negligible share of GDP - the famous fable of the elephant and the rabbit (Diemer et al., 2019). Teasley understood quickly that the energy was interrelated with material use, so he wanted to know the implications of using different packaging options. So the first intuition of LCA was the comparative analysis of packaging under environmental aspects, especially with regard to resource conservation and energy saving (Diemer, 2023). The publication of the report of Club of Rome "Limits to Growth" (1972) and the oil crisis (1973) definitively linked the fate of our economies not only to the depletion of natural resources, but also to the environmental and social damages caused by unlimited economic growth.

In the middle of 1970s, the history of LCA connected with the *Resource Conservation and Recovery Act* (RCRA), enacted by Congress on October 21, 1976, in order to address the problems associated with waste disposal (EPA, 1975). RCRA was built on the foundation of the Solid Waste Disposal Act of 1965 and the Resource Recovery Act of 1970. It was developed "*to provide technical and financial assistance for the development of management plans and facilities for the recovery of energy and other resources from discarded materials, for the safe disposal of discarded materials and to regulate the management of hazardous* waste" (Congress of the US, 1976). In the 1980s, many amendments to the *Resource Conservation and Recovery Act* (RCRA) were voted on. The amendment of 1984 serves as an example of contemporary environmental law-making where the legislative goals are often broad and the “real world” objectives are specific, precise, and intermixed with many practical problems of analytical chemistry, toxicology, and environmental engineering (Howard, 1986). All the products were analyzed from "*Cradle to Grave"*. The basic idea behind the term LCA is that all environmental burdens connected with a product or service have to be assessed, back to the raw materials and down to waste removal (Klöpffer, 1997).

Although there was a demand for environmental health data on chemicals, there was no global scientific organization able to talk about the science behind the regulations being developed. The Society of Environmental Toxicology and Chemistry (SETAC) was founded in 1979. SETAC had three strengths: its global scale, its tripartite membership and governance, and its scientific base (Fava et al., 2014). Because SETAC was developed on an international scale, it has been able to address global environmental issues. From 1990 to 1993, SETAC North America and SETAC Europe shaped the basic structure of LCA in a series of workshops. The workshop, ‘A Technical Framework for Life Cycle Assessments’, held August 18–23, 1990, at Smugglers Notch, Vermont, was organized by SETAC to develop a framework and consensus on the current state of LCA and research needs for conducting life cycle assessments. Although life cycle assessments have been used before the name was coined, this workshop report is the first document which presented the name of the method. The following workshops, Leiden (1991), Sandestin (1992) and Wintergreen (1992) formed a step by step process (Gabatthuler, 1997) culminating in the *Code of Practice* workshop of Sesimbra (1993). The results of these workshops are illustrated by the SETAC Triangle (Fava et al., 1992). LCA is structured around four main areas : (i) Goal definition and scoping, (ii) Inventory Analysis, (iii) Impact Assessment, and (iv) Improvement Assessment.

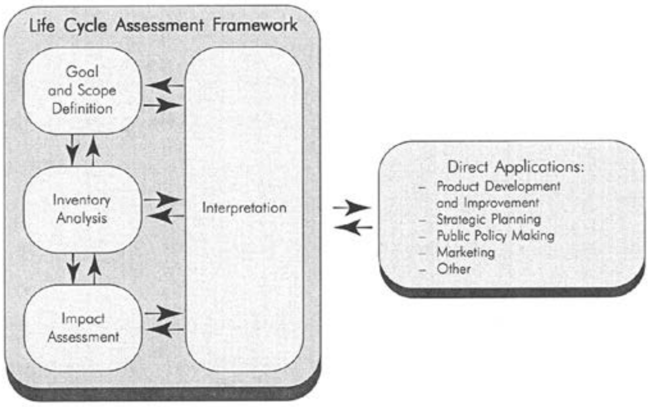
Figure 1 : *SETAC Triangle of LCA*



Source: Fava et al. (1991, p.1), Klöpffer (1997, p. 223)

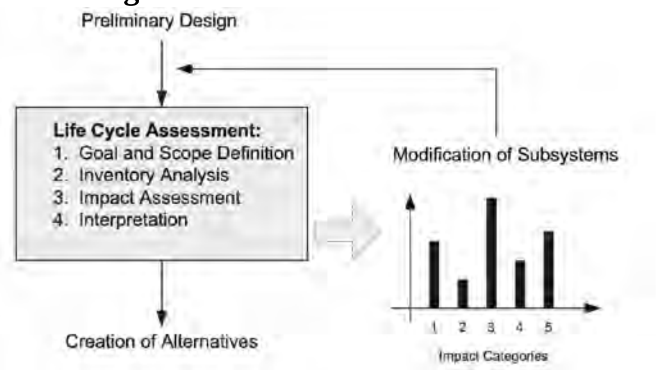
Shortly after the workshop, in November 1993 (Paris), the ISO standardization process (ISO Technical Committee, TC 207, Subcommittee SC5) was initiated (Marsmann, 1997). For Ryding (1999, p. 307), one reason for this initiative was "*growing awareness among many delegates in TC 207 of the usefulness of LCA as a methodological tool for the continuous process in identifying environmental aspects within the framework of environmental management systems according to ISO 14001*". The structure proposed by ISO differs from the SETAC structure (Lecouls, 1999) only in the last element which is called "*interpretation*" in the international standard 14040 (Klöpffer, 1997). For Klöpffer (2014, p. 9), two reasons could explain this replacement: (1) the fear by industry that an improvement assessment may become obligatory for all LCAs; (2) the fact that an LCA may also serve different purposes, not only product improvements. The double arrows symbolize that the different phases of the LCA may be modified if new aspects emerge during the performance of an LCA. A list of non exhaustive *Direct applications* "Product Development and improvement, strategic planning, public policy making, marketing and other " is given in Figure 2a. As shown in Figure 2b, the four box framework (with Goal and Scope Definition, Inventory Analysis, Impact Assessment, interpretation) split the LCA design in four distinct stages and successive series of ISO LCA Standards: *14040 General Principles* (1997), *14041 Life Cycle Inventory Analysis, LCI,* (1998), *14042 Life cycle Impact Assessment, LCIA* (2000) and 14043 Interpretation (2000). ISO 14040 quickly became the official model of environmental life cycle. A success that Pryshlakivsky and Searcy (2013) also attribute to the position of 14040 ISO series vis-à-vis the overall ISO 14000 family of standards. The ISO 14040 was conceived as a supplementary tool of an overall Environmental Management System (EMS) platform centered on 14001 : "*It may be stated that a useful goal, of ISO 14040 series is to inform ISO 14001 with regard to the latter standard's requirement of continuous improvement to maintain compliance with the statut*" (2013, p. 116).

Figure 2a: *LCA design (ISO 14040)*



Source: Klöpffer (1997, p. 225, 2014, p. 9)

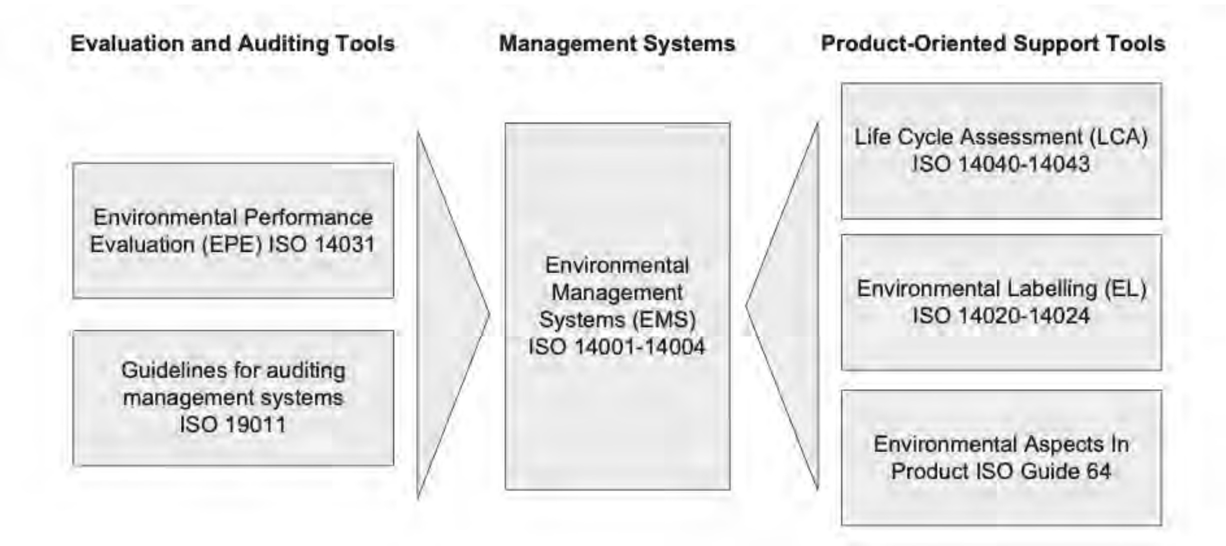
Figure 2b: *Four Box Framework*



Source: Gasafi et al. (2004)

Fig. 3 presents the inter-relations between ISO standards, through the Environmental Management System (Fet, 1998).

Figure 3: *EMS platform of ISO Standards family*



Source: Fet (1998), Pryshlakivsky & Searcy (2013)

Soon after ISO 14040 standard publications, many critiques emerged. Some of these included the LCA as too nascent, a dissimilar peer review process to academic peer review, too many value judgments, and not enough normative analysis. The LCA process created an artificial limit to the development and the emergence of new assessment methods, the question of metrics and indicators of sustainability was a weakness, economic analysis was under-developed (LCA was more focused on industrial engineering, industrial ecology, or sustainable management). Pryshlakivsky and Searcy (2013, p. 117) compiled these shortcomings in Table 1.

Table 1: *Critics of ISO 14040 standard*

Critique	Addressed?	Comments
LCA is too nascent (Hertwich and Pease, 1998).	No	The earliest LCA studies date back to the 1970s (Jensen et al., 1997).
Peer review process not similar to extant peer review (Klöpffer, 1997).	No	This was addressed to some extent in 2006 by the addition of the critical review definition and sections; however, this process need not be peer reviewed and is not necessarily within the purview of an international standard.
Lack of clarity in language (Hertwich and Pease, 1998; Lecouls, 1999; Lee and Xu, 2005; Tsoutas et al., 2010)	Yes	Substantive revisions and additions to literature.
Too many value judgments, not enough normative or scientific factors (Hertwich and Pease, 1998).	No	This can have consequences, but these are acknowledged with normalization (section 4.4.3.2), grouping (section 4.4.3.3), and weighting (section 4.4.3.4). Weighting is not to be used in comparative assertions for public disclosure (section 4.4.5).
Limit the development and emergence of new assessment methods (Hertwich and Pease, 1998).	No	This could be a problem within LCA in general. Hertwich and Pease (1998) do not quantify this.
Does not address: 1. Uncertainty (UNEP, 2005). 2. Weighting (Udo de Haes and Jolliet, 1999; Ryding, 1999). 3. Valuation (Udo de Haes and Jolliet, 1999; Ryding, 1999). 4. Allocation (Ekvall and Finnveden, 2001).	 Yes Yes No Yes	The allocation, uncertainty and weighting are addressed within the new standard and revised in some instances. Valuation is an economics technique such that it is not necessarily within the purview of LCA. Normalization is a facet of LCIA.
Does not contain any metrics or indicators of sustainability (Ny et al., 2006).	No	This is the purview of environmental performance evaluation, environmental impact assessment and risk assessment (Section 4.4.1).
Economic analysis (Norris, 2001; Reich, 2005).	No	Not within the purview of LCA. However, Allocation Procedures for Reuse and Recycling (Section 4.3.4.3.4) makes reference to economic values of recycled materials for purposes of allocation.

Source: Pryshlakivsky and Searcy (2013, p. 117)

These critics were discussed at the International Life Cycle Assessment and Management Conference in Seattle (2003). A draft list of improvements for a new achievement of the ISO 14040 has been proposed. New topics (new standard 14025 'Environmental Labelling and Declaration Type III') and revisions of the ISO Standards (14040, 14041, 14042, 14043) were formulated in Mexico City (January 2005) by the ISO Technical Committee 207 (Klüppel, 2005). A new version of ISO 14040 was published in 2006. The family of ISO 14040 standards frames the requirements for conducting Life Cycle Assessments (LCA) while leaving the actual mechanics of analysis - data collection, normalization, calculation, interpretation, etc. - to the practitioner (many sections are transcriptions from 1997 - 2000 requirements). ISO 14040 (2006) specifies the principles and framework for carrying out life cycle assessments, including:

A. the definition of LCA objectives and scope,
B. the life cycle inventory phase,
C. the life cycle impact assessment phase,
D. the life cycle interpretation phase,
E. the communication and critical review of the life cycle assessment,
F. the limitations of life cycle assessment,
G. the relationship between life cycle assessment phases, and
H. the conditions for use of value choices and optional elements (ISO, 2006).

ISO 14040 deals with life cycle assessment studies and life cycle inventory studies. It does not describe in detail the technique of life cycle assessment, nor the specific methodologies of each of its phases (Finkbeiner et al., 2006). The intended application of the LCA or LCI (Life Cycle Integration) results should be taken into account when defining the objectives and scope of application (Jaafari, 1999). Pryshlakivsky and Searcy (2013, p. 117) have identified the main changes in ISO 14040. The new version deleted the section of "Limitations of LCA techniques", introduced definition of product (including services as intellectual property), process, flows, release, etc., or expanded existing definitions (system boundaries). An overview of these changes is found in Table 2 below.

Table 2: *Definitions from ISO 14040, comparison between 1997 and 2006*

ISO 14040:1997		Altered?	Degree	ISO 14040:2006	
Boundary	Allocation	✓	Minimal	Boundary	Allocation
	Functional unit	✓	Minimal		Functional unit
	Product system	✓	Minimal		Product system
	System boundary	✓	Significant		System boundary
	Unit process	✓	Significant		Unit process
Material	Ancillary input	✓	Minimal	Material	Ancillary input
	Co-product	✓	Minimal		Co-product
	Elementary flow	×			Elementary flow
	Energy flow	×			Energy flow
	Environmental aspect	×			Environmental aspect
	Environmental mechanism	×			Environmental mechanism
	Feedstock energy	✓	Minimal		Feedstock energy
	Input	✓	Minimal		Input
	Intermediate flow	✓	Minimal		Intermediate flow
	Intermediate product	✓	Minimal		Intermediate product
	Life cycle	×			Life cycle
	Output	✓	Minimal		Output
	Process energy	✓	Minimal		Process energy
	Raw material	×			Raw material
	Reference flow	✓	Minimal		Reference flow
	Waste	✓	Minimal		Waste
Method	Category endpoint	✓	Minimal	Method	Category endpoint
	Characterization factor	✓	Minimal		Characterization factor
	Comparative assertion	×			Comparative assertion
	Completeness check	✓	Minimal		Completeness check
	Consistency check	✓	Minimal		Consistency check
	Data quality	✓	Minimal		Data quality
	Evaluation	✓	Minimal		Evaluation
	Impact category	×			Impact category
	Impact category indicator	×			Impact category indicator
	Life Cycle Assessment	×			Life Cycle Assessment
	Life Cycle Impact Assessment	✓	Minimal		Life Cycle Impact Assessment
	Life Cycle Interpretation	✓	Minimal		Life Cycle Interpretation
	Life Cycle Inventory analysis	✓	Minimal		Life Cycle Inventory analysis
	Life Cycle Inventory analysis result	✓	Minimal		Life Cycle Inventory analysis result
	Sensitivity analysis	✓	Minimal		Sensitivity analysis
	Sensitivity check	×			Sensitivity check
	Transparency	×			Transparency
	Uncertainty analysis	✓	Minimal		Uncertainty analysis
Misc.	Interested party	×		Misc.	Interested party
Removed	Final product			Added	Critical review
	Fugitive emission				Cut-off criteria
	Practitioner				Process
					Product
					Product flow
					Releases

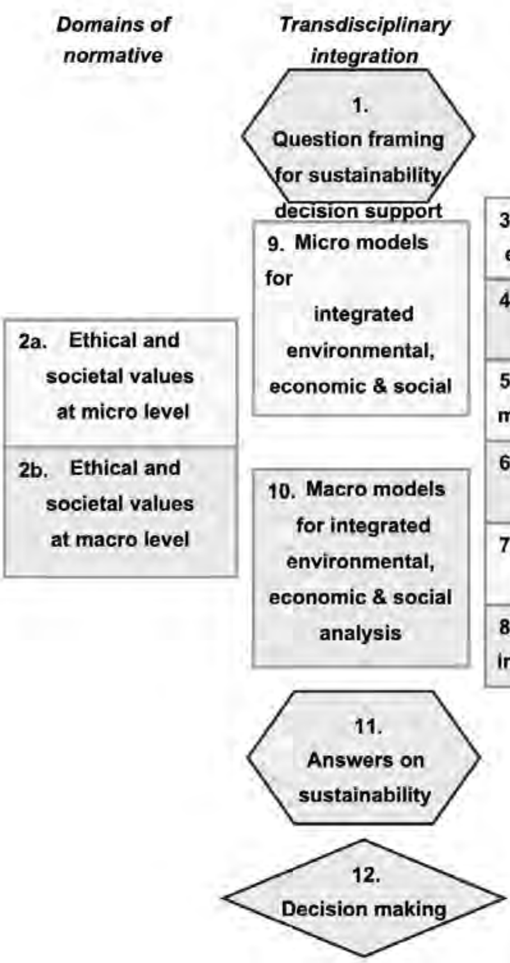
Source: Pryshlakivsky and Searcy (2013, p. 120)

But the most significant element coming from the new revision of ISO 14040 series was the publications of LCA case studies, proving that LCA was a relevant tool for sustainability assessment. Parker et al. (2007, p. 1120) noted that "*LCAs have been applied to a wide variety of energy technologies including nuclear, wind, coal as well as electrical networks*". Each stage of the product life cycle is evaluated in detail. Data on the energy and emissions from each stage are then gathered and, where not available, justifiable assumptions are made. For example, Pehnt (2006, p. 62) used dynamic LCA to challenge renewable energy technologies (this concerns the development of products, their production processes, as well as their technical performance and the development of so-called background systems). Schau and Fet (2008) explored the suitable functional units, system boundaries and allocation procedures for LCA in food production in general, and the product category rules (PCR) and environmental product declaration (EPD) for food products specifically. The term EDP is used on environmental product declarations that belong to a type III-programme which requires an LCA according to the ISO 14040 - standards, an approval of the LCA and a third party verification (ISO 14025, 2006). Fava, Baer, and Cooper (2009) presented the increasing demands for LCA in North America, especially with a focus on the integration of life cycle approaches into greener buildings, the development of life cycle-based carbon footprint protocols and the rapid development of requirements from retails companies demanding environmental performance of consumer goods.

Common LCA data sources and defined approaches to measure and report on a product's carbon footprint have been developed and there is a movement to create a national life cycle inventory (LCI) database. All these efforts to catch carbon footprint and eco-efficiency practices in LCA (Huppes, Ishikawa, 2009) were widely praised by the World Business Council for Sustainable Development (WBCSD). Heijungs, Huppes and Guinée (2010) explored the scientific basis of life cycle based tools for sustainability, and then the concept of LCA. Using the framework of Huppes and Ishikawa (2009), they identify different models (technical, physical, environmental, micro-economic, meso and macro-economic, cultural, ethical and societal values, integrated) to propose a deeper and broader LCA, separating the empirical knowledge (the facts), the normative position (the values), and the transdisciplinary (integration). Figure 4 contains a framework for Lifecycle Sustainability Analysis by Heijungs et al. 2010.

In the 2010s, a lot of international organizations and institutions recognised the importance of LCA. In his report *The Future We Want*, UN (2010) considered "*the importance of adopting a life cycle approach and of further development and implementation of policies for resource efficiency and environmentally sound waste management*". UNEP (2009, 2011) published the guidelines on social LCA (SLCA) and the framework on Life Cycle Sustainability Assessment (LCSA). LCSA refers to the evaluation of all environmental, social and economic negative impacts and benefits in decision making processes towards more sustainable products throughout their life cycle.

Figure 4: *Framework for Life Cycle Sustainability Analysis*

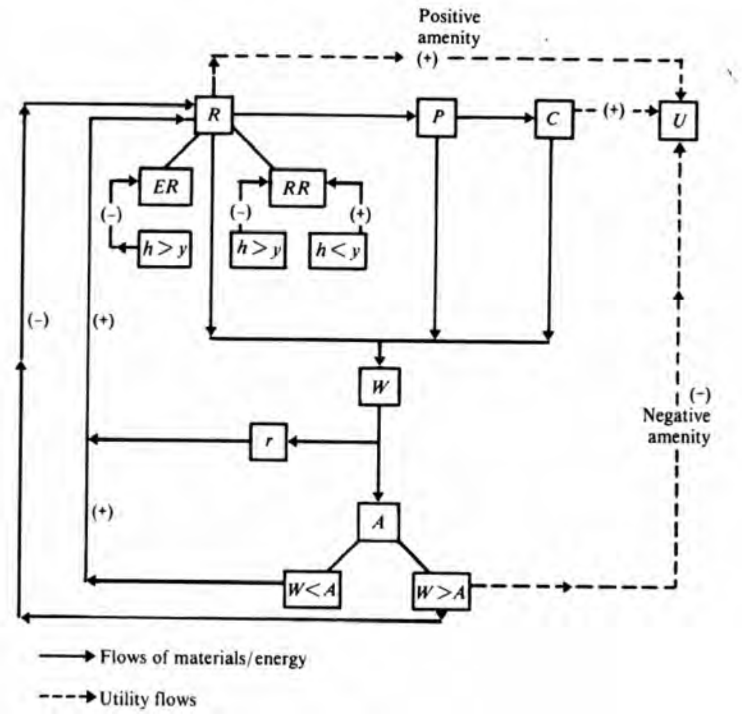


Source: Heijungs et al. (2010, p. 426)

This broad approach is presented as a complementary analysis for circular economy (Pena et al., 2021). The circular economy (CE) was drawn primarily on the precepts of ecological economics and industrial ecology (Ghisellini et al., 2015), incorporating in the process the economy of functionality (Stahel & Reday, 1977, Stahel, 1982, Stahel & Reday, 1982) and the sharing economy (Henry et al., 2021).

In *Ecological economics*, one of the main arguments in favor of a representation of the circular economy refers to the notions of open and closed systems, and thus to the relationship between economy and ecology. In a chapter entitled "*The Economics of the Coming Spaceship Earth*" and published in a book edited by Henry Jarrett, Environmental Quality in a Growing Economy, Kenneth Boulding (1966) returns to this opposition, comparing what he calls the *Cowboy Economy* with the *Spaceman Economy*. According to Boulding, economists in particular "*have failed to come to grips with the ultimate consequences of the transition from the open to the closed earth*" (1966, p. 4). Boulding introduces here two of the essential components of a circular economy, (1) the characterization of a variable as a flow or a stock in a homeostatic state (consumption is a flow, natural resources are stocks), (2) the question of product durability, and more precisely the gains to be made by improving product lifetimes: "*I suspect that we have underestimated, even in our spendthrift society, the gains from increased durability, and that this might very well be one of the places where the price system needs correction through government-sponsored research and developmen*t" (1966, p. 13). More recently, Pearce and Turner (1990) used the ideas of Boulding (planet earth as a spaceship, thermodynamics) to formally define the term circular economy (Rizos, Tuokko, Behrens, 2017). The relation between environment and economy that we could assimilate to a materials balance model, incorporates three economic functions of the environment: "*resource supplier, waste assimilator and source of utility*" (Pearce, Turner, 1990, p. 35). They are economic functions because they all have a positive economic value. Resources (R) are an input to the production process which provides consumer (C) and capital (K) goods for consumption. Consumption of goods creates utility (U). Waste (W) is produced at all three stages: resources processing, production and consumption of goods. Some waste is recycled (r) but the majority goes to the environment (as a waste sink). The figure 5 presents the circular economy described by Pearce and Turner. Flows of materials and energy follow the laws of thermodynamics in a closed system (Diemer; Sarr, 2023). Flows of utility are interconnected with consumption. Pearce and Turner added this flow to highlight the third function of the environment: it supplies utility directly in the form of aesthetic enjoyment and spiritual comfort but if waste is excessive from assimilative capacity, A, the economic process should damage the function of the environment.

Figure 5: *The Circular Economy*



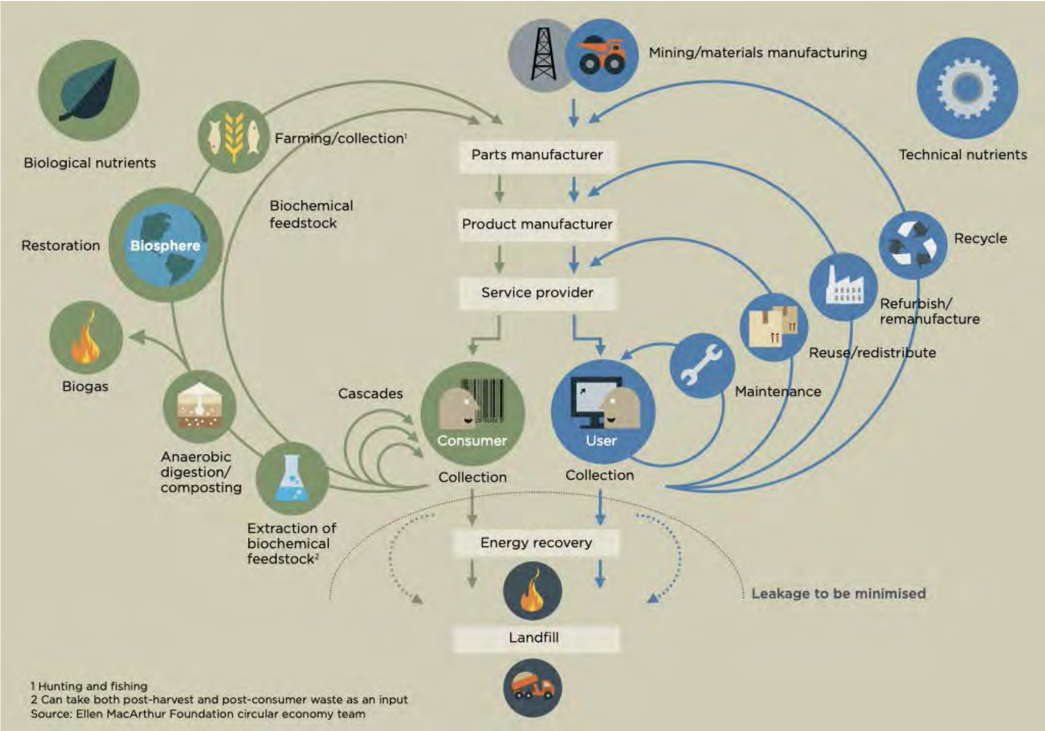
Source: Pearce, Turner (1990, p. 36)

In *Industrial ecology*, mapping materials and energy flows is supported by a driving force, the eco-efficiency. Eco-efficiency refers to industrial metabolism (Esquissaud, 1990). It is more precisely a question of quantitatively and qualitatively measuring the physical dimension of economic activities, namely the flows and stocks of materials and energies inherent in any industrial activity (Ayres 1989). In a book titled *Changing Course: Reconciling Business Development and Environmental Protection* (1992), Stephan Schmidheiny and the BCSD (Business Council for Sustainable Development) associated the methodology of industrial metabolism with the principle of eco-efficiency. According to Erkman, this methodology involves "*establishing mass balances, estimating fluxes and stocks of matter, tracing their complex routes and dynamics, but also pinpointing their physical and chemical state*" (Erkman, 1998, p. 56). For companies, this accounting is carried out in the form of an input-output matrix and a life cycle analysis (LCA). These "environmental balances" make it possible to control exchanges, to know the level at which they occur, to know how they are structured and how they destructure the environment. From an economic point of view, industrial metabolism includes all the flows of matter and energy that allow the economic system to run, i.e. to produce and consume (Hertwich, 2005). It thus makes it possible to change our perception of the value of a good (generally associated with the law of supply and demand, the market price) by including ecological, social and cultural factors via flows of materials, energies and information (Passet, 1996). The limits of this approach is to put society back into the hands of the engineers: "*Engineers are accustomed to contending with a variety of design constraints, from the most rigid thermodynamic laws to budgetary constraints to issues of social justice. Ecological constraints add one more set of considerations to the list. Engineering designs are now expected to result in products and management plans whose use or implementations will not endanger important ecological conditions and processes*" (Schulze, 1996).

This connection between industrial ecology and circular economy is clearly mentioned in the different reports of the Ellen MacArthur Foundation (2011, 2013). For EMF (2013, p. 7), Circular Economy "*is an industrial system that is restorative or regenerative by intention and design*". It replaces the end of life concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems and within these business models. Strategies for Circular Economy aim to preserve natural, physical, human and social assets by shifting the material composition of consumables from technical towards biological nutrients and by having those cascades through different applications before extracting valuable feedstock and finally re-introducing their nutrients into the biosphere.

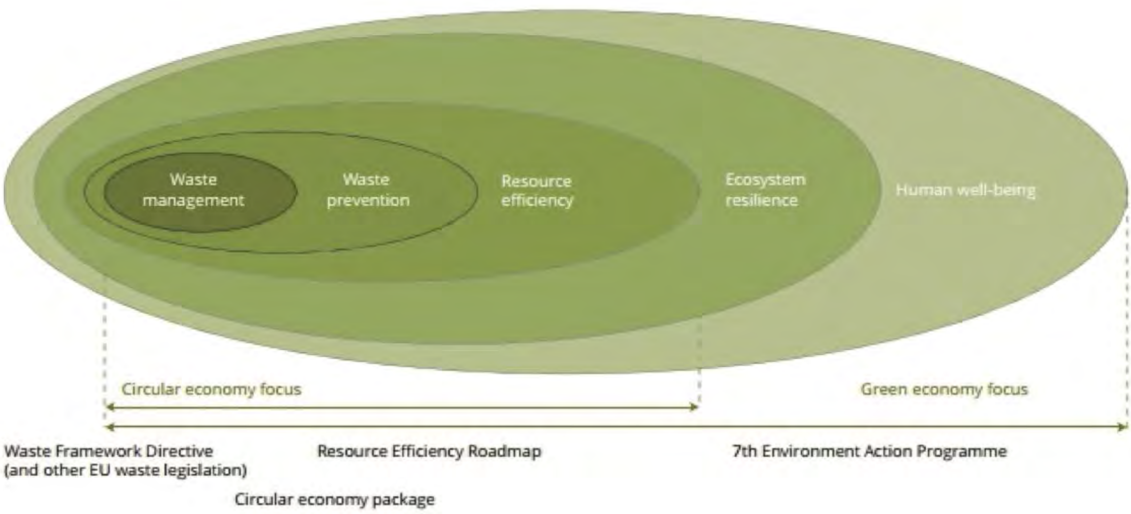
The EMF Report (2013) uses the two types of material flows described by Braungart and McDonough in *Cradle to Cradle* (2008). This international best seller tries "*to put human beings in the same species picture as other living things and to us, as a misuse of material resources is not just suicidal for future human generations but catastrophic for the future of life*" (2008, p. 3). It is an approach to support the biosphere on one hand and the technosphere on the other hand. Cradle to Cradle design is an answer to the Cradle to Grave design which dominates modern manufacturing. Cradle to Grave means that most of the materials extracted to produce goods become waste immediately, that the product itself lasts less and less, that it's cheaper to buy a new product than to repair the original. Products are "*built in obsolescence*" (2008, p. 28). With Circular Economy, Life Cycle Assessment (LCA) jumped from the case studies to the paradigm of sustainability (Diemer et al., 2021), green economy (Krugman, 2010) or degrowth (Diemer, 2023). Circular economy may improve designs to bring more components into the remanufacturing loop, enabling products to cycle not only once but potentially multiple times through the product life cycle. Circular Business Models (CBM) such as leasing models give manufacturers strong control over products over the life cycle. They could address challenges as a shorter product life cycle. Europe has promoted these challenges since the middle of 2000s, with the *Waste Framework Directive* (Directive 2008/98/EC), *the Roadmap to a Resource Efficient Europe* (EC, 2011), *the General Union Environment Action Programme* (EP, 2013, Decision 1386) and *the Green Deal* (EC, 2019).

Figure 6: *Circular economy, industrial system and restorative design*



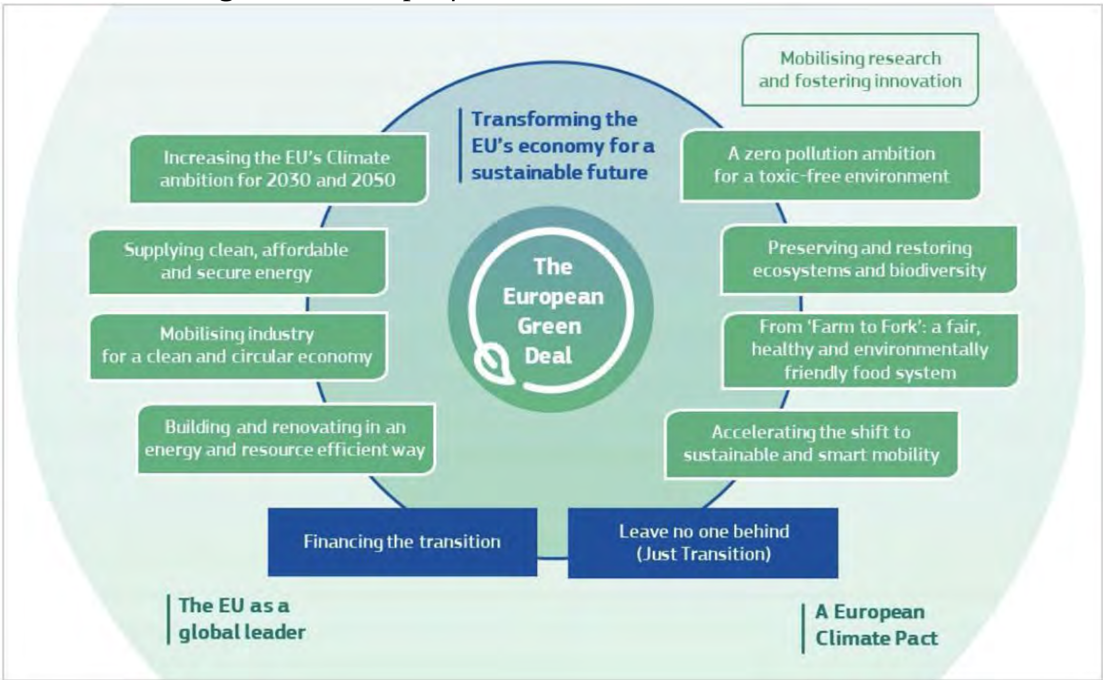
Source: EMF (2013, p. 24)

Figure 7a: *Europe, from Waste Directive to Green Deal*



Source: Almut et al. (2016)

Figure 7b: *Europe, from Waste Directive to Green Deal*



Source: Diemer, Dierickx (2021)

If the *Roadmap to a Resource Efficient Europe* (2013) was concerned by transforming the economy onto a resource-efficient path to increase competitiveness and new source of growth and job through cost savings from improved efficiency, commercialisation of innovations and better management of resources over their whole life cycle, the adoption of the *Circular Economy Action Plan* (EC, 2019) aimed to accelerate and continue the transition to a circular economy. In March 2020, the action plan was associated with the EU industrial strategy in order to mobilize the industrial sector and all the value chains towards a model of sustainable and inclusive growth. **Leverage points** have been identified:

1. Move away from a linear economy and mitigate its associated impacts on the environment;
2. Boost design, production and marketing of sustainable products;
3. Empower consumers to contribute to the circular economy;
4. Reduce waste generation and support the modernisation of certain waste laws ;
5. Identify actions to address high impact sectors (textiles, construction, electronics, plastics);
6. Integrate social and geographic impacts of circular economy;
7. Develop innovation and investment opportunities for circular business models.

Cycle Assessment is clearly mentioned in the *Construction and Buildings sector*. EC (2020, p. 14) reminds us that the built environment has a significant impact on many sectors of the economy, on local jobs and quality of life. It requires vast amounts of resources and accounts for about 50% of all extracted material. The construction sector is responsible for over 35% of the EU's total waste generation. Greenhouse gas emissions from material extraction, manufacturing of construction products, construction and renovation of buildings are estimated at 5-12% of total national GHG emissions. Greater material efficiency could save 80% of those emissions. To exploit the potential for increasing material efficiency and reducing climate impacts, the Commission launched a new comprehensive Strategy for a Sustainable Built Environment. ***This strategy promotes circularity principles throughout the lifecycle of buildings by using level(s) to integrate Life Cycle Assessment (LCA) in public***

procurement and the EU sustainable finance framework and exploring the appropriateness of setting carbon reduction targets and the potential of carbon storage. The concept of Level(s) - included in the European Framework for Sustainable Buildings - is quite interesting, it provides a common language for assessing and reporting on the sustainability performance of buildings. It's a simple entry point for applying circular economy principles in the built environment. The concept of Level(s) offers an extensively tested system for measuring and supporting improvements, from design to end of life. The level(s) common framework is based on six macro-objectives that address key sustainability aspects over the building life cycle. The sustainability indicators within each macro-objective describe how the building performance can be aligned with the strategic EU policy objectives in areas such as energy, material use and waste, water, indoor air quality and resilience to climate change.

Table 3: *Macro-objectives to address key sustainability*

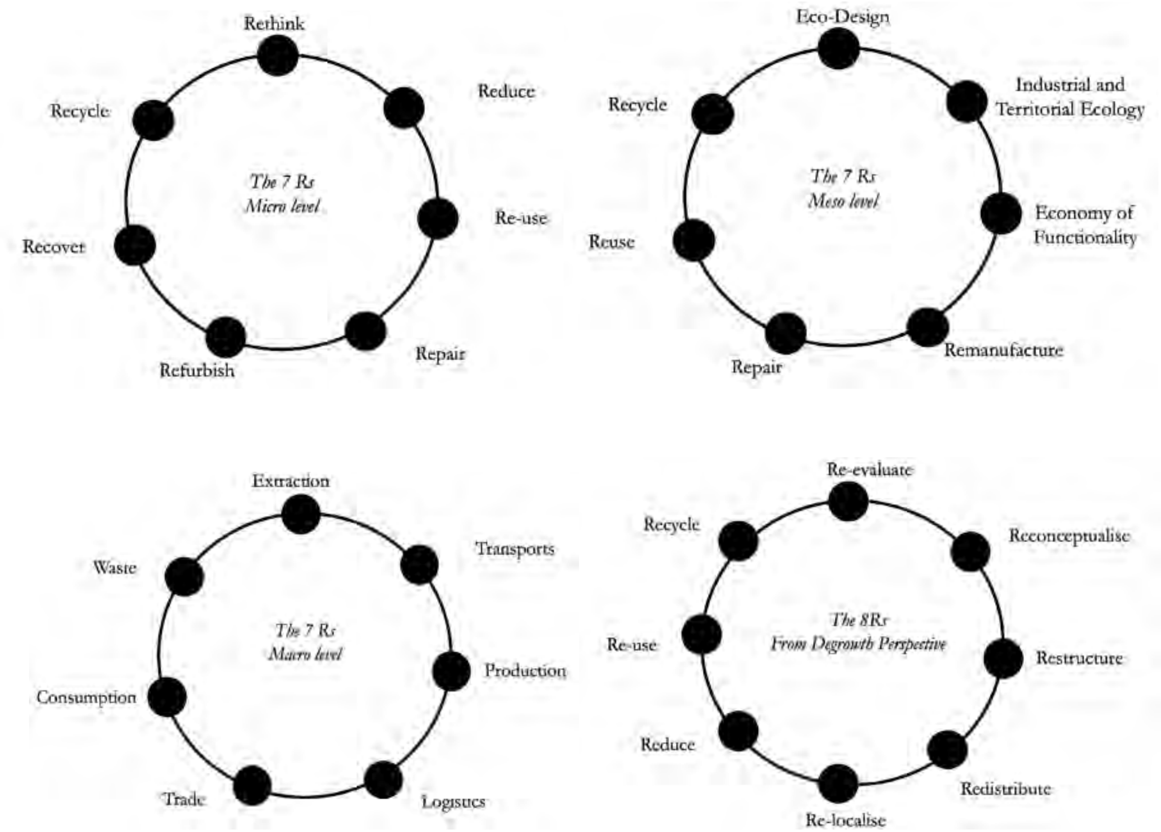
Macro-objectives	Targets	Indicators
1. Greenhouse gas emissions along a buildings life cycle	Minimize the whole life carbon output, consider both energy consumption during the use phase of the building and embodied energy.	1.1 Use stage energy performance (kWh/m2/yr) 1.2 Life cycle Global Warming Potential (CO2eq./m2/yr)
2. Resource efficient and circular material life cycles	Optimize the building design to support lean and circular flows, including: ● Building materials use and quantities ● Minimize construction and demolition waste generated to optimize material use ● Replacement cycles and flexibility to adapt to change ● Potential for deconstruction as opposed to demolition	2.1 Bill of quantities, materials and lifespans 2.2 Construction & Demolition waste and materials 2.3 Design for adaptability and renovation 2.4 Design for deconstruction, reuse and recycling
3. Efficient use of water resources	Use water efficiently, particularly in areas of identified long-term or projected water stress.	3.1 Use stage water consumption (m3/occupant/yr)

4. Healthy and comfortable spaces	Create buildings that are comfortable, attractive and productive. This includes four aspects of the quality of the indoor environmental quality: ● The indoor air for specific parameters and pollutants ● The degree of thermal comfort ● The quality of artificial and natural light and associated visual comfort ● The capacity of the building fabric to insulate occupiers from internal and external sources of noise	4.1 Indoor air quality 4.2 Time outside of thermal comfort range 4.3 Lighting and visual comfort 4.4 Acoustics and protection against noise
5. Adaptation and resilience to climate change	Futureproof building performance: ● Adapt to changes of future climate impacting on thermal comfort ● Make the building more resilient and resistant to extreme weather events (including flooding: fluvial, pluvial and coastal). ● Improve the building design to reduce the chances of pluvial/fluvial flood events in the local area (i.e. increasing sustainable drainage).	5.1 Protection of occupier health and thermal comfort 5.2 Increased risk of extreme weather 5.3 Sustainable drainage
6. Optimized life cycle cost and value	Long term view of the whole life costs and market value of more sustainable buildings, including: ● Life cycle costs (construction, operation, maintenance, refurbishment and disposal). ● Encourage the integration of sustainability aspects into market value assessment and risk rating processes and ensure that this is done as informed and transparent as possible	6.1 Life cycle costs (€/m²/yr) 6.2 Value creation and risk factors

Source: https://environment.ec.europa.eu/topics/circular-economy/levels

LCA (and LCSA) is one of the key value product chains. Every sector (electronic, battery and vehicles, packaging, plastics, textiles, construction and building, food, water and nutrients, etc.) is concerned and has to contribute to the sustainable product policy framework. Practices and strategies for implementing LCA (and LCSA) in circular economy have to combine the micro, meso and macro scales, from 3Rs (Reduce, Reuse, Recycle) to 7R (Rethink, Reduce, Re-use, Repair, Refurbish, Recover, and Recycle), from extraction to waste, from Ecodesign to Recycling.

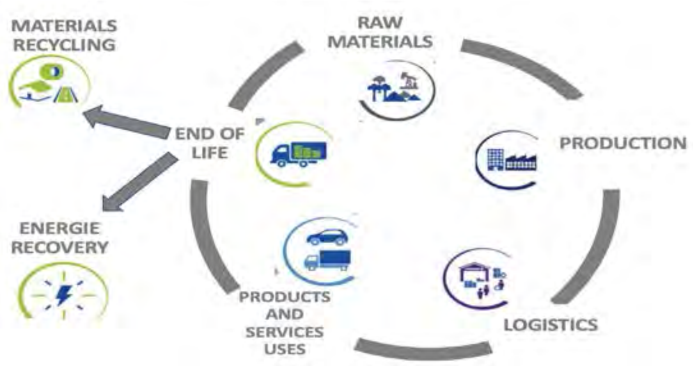
Figure 8: *Implementing LCSA in Circular economy*



Source: Diemer (2021)

Indeed, LCA as a technique is used to evaluate not only environmental, economic, and social impacts of a product throughout its life cycle (raw materials, production, logistics, products and services use, end of life), but also those that can be assigned to baskets of goods, companies, households, countries, and the planet (Norris, 2014). LCSA (Life Cycle Sustainability Assessment) is carried out on all its product ranges, introducing an eco-design assessment. This global approach is based on the guidelines of ISO 14 040 - Life Cycle Assessment and ISO 14 006 - Guidelines for integrating eco-design. The family of LCA ISO Standards is a guide to assess environmental, economic, and social impacts of their business model. The 4Rs or the 7Rs are challenging the equal balance of People, Profit and Planet. The case of the Michelin Company may be used to **illustrate the connection between Life Cycle Sustainability Assessment and Circular Economy**

Figure 9 : *Pathways for Life Cycle Sustainability Assessment at Michelin Company*



Source : Debladis, Diakhate, Goineau, Taillandier, Diemer (2019)

2. The components of LCA according to ISO 14040 and the integration in stratey

The different components of the LCA are (i) goal definition and scoping, (ii) inventory analysis, (iii) impact assessment, and (iv) interpretation.

2.1 Goal and scope Definition

The goal definition is of central importance to LCA (Klöpffer, 1997). It defines the reason for performing a specific study and the system to be analysed, but also the:

- boundaries of the system (what to include and what to exclude – these boundaries may be technical, geographical or temporal,
- functional unit for quantitative description and model,
- scope of the product system (decide which activities and processes belong to the life cycle of the product),
- rules and the assumptions (data, allocation rules for coproducts, open loops for recycling, aggregation),
- kind of impact assessment and valuation (selecting the assessment parameter),
- group to be addressed by the study (interna, general public, politics…),
- relevant perspective to apply, added studies (Kellenberger, Alhtaus, 2009), and
- need to perform critical review (comparative assertion).

The goal definition based on the ISO standard requirements generally contains six aspects (Bjorn, Laurent, Owsianiak, Olsen, 2018):

1. intended applications of the results (all LCAs involve studying one or more product systems and this can be used in several applications : comparing environmental impacts of specific goods and services, identify the parts of the product system that contribute most to its environmental impact…);
2. limitations due to methodological choices (this aspect can be seen as a critical reflection of what the LCA results can and can not be used for);
3. decision context and reasons for carrying out the study (it's possible to define three types of decisions context, the micro-level decision support, the meso/macro level decision support and the accounting, the reasons should be clearly connected to the intended application of results and specifically address drivers and motivations with respect to decision making;
4. target audience (to whom the results of the study are intended to be communicated: consumers, companies, managers, NGOs…);
5. comparative studies to be disclosed to the public (the ISO standard specifies a number of requirements on the conduct and documentation of the study and an external review process);
6. commissioner of the study and other influential actors (this step of the goal definition is meant to highlight potential conflicts of interest to readers of the study).

A scope definition consists of the following nine scope items (Bjorn, Laurent, Owsianiak, Olsen, Corona, Hauschild, 2018): (1) Deliverables, (2) Object of the assessment, (3) LCI modelling framework and handling multifunctional process, (4) System boundaries and completeness requirements, (5) representativeness of LCI data, (6) Preparation of the basis for the impact assessment, (7) Special requirements for system comparisons, (8) Needs for critical review, (9) planning reporting of results.

2.2 Inventory Analysis

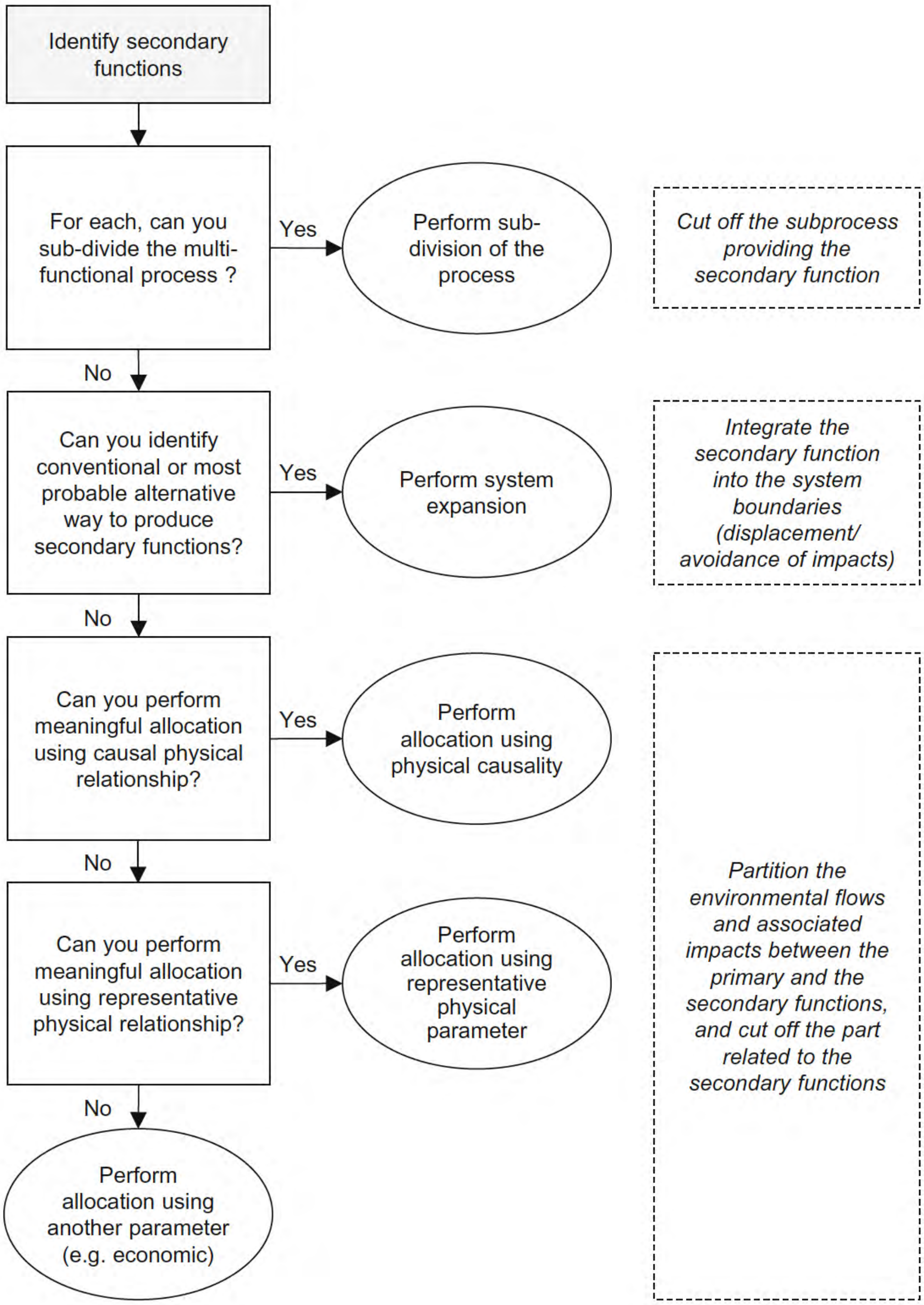
The inventory analysis considers that all activities related to the production of one functional unit have to be analysed concerning the following component (Klöpffer, 1997) : raw material extraction, intermediate products, the product or service itself, the use phase and the removal of waste. Energy, transports and auxiliary products are included when they are used as inputs. Outputs are co-products, emissions to air, water and soil, waste heat and solid wastes. It's possible to provide practical guidance on how to perform a Life Cycle Inventory (LCI) analysis using an iterative approach to LCA. LCI analysis is structured around six steps: (1) Identifying processes for the LCA model; (2) Planning and data collect; (3) Constructing and quality checking unit processes; (4) Constructing LCI model and calculating LCI results; (5) Preparing the basis for uncertainty management and sensitivity analysis; (6) Reporting.

2.2.1 Identifying processes for the LCI model

The first step of the LCI is to start with the reference flow and construct the entire foreground system (Bjorn, Moltesen, Laurent, Owsianiak, Corona, Birkved, Hauschild, 2018). At the level 0, the unit process having the reference flow (as product output) should be identified. At the level 1, the processes required to deliver flows that will be physically embodied in the reference flow should be identified. At the level 2, the processes required to deliver flows that perform a supporting function to the level 0 process have to be presented. At level 3, the processes required to deliver services to the level 0 processes should be identified. At level 4, processes required to produce and maintain the infrastructure that enables the level 0 process have to be identified. Upstream and downstream processes have to be identified. When this procedure is carried out, it is possible to identify all multifunctional processes. ISO hierarchy can be used for solving multifunctionality (see Figure 10). According to this hierarchy, the preferred solution is the subdivision of the concerned process, and if it is not possible, system expansion or allocation.

Subdivision is the most relevant solution to multifunctionality by increasing the modeling resolution and subdividing the process into minor units which can unambiguously be assigned to either of the functional outputs. Many levels of details are introduced in the modeling process. So when a factory produces many products (minimum of two), the subdivision approach may lead to the realization that the factory contains a number of processes and that the processes needed for the production of the first product are physically separated from the processes needed for the production of the second product, and so on. This approach makes it difficult, especially when it is not possible to physically separate the metabolic processes. If subdivision fails, ***system expansion*** must be done. In the comparison of two processes, the system expansion approach means expanding the second process with the most likely alternative way of providing the secondary function of the first process. System expansion is mathematically identical to crediting the studied product system with the avoided production of the secondary function that would alternatively have been produced and delivered somewhere else in the technosphere. For example, a production system that includes incineration can be credited for the avoided impacts from the production of heat and electricity by subtracting the avoided elementary flows in the inventory process. When system expansion is not feasible or in conflict with the goal definition, the ISO standard recommends dividing the inputs and outputs of the multifunctional processes (or system) between the different products or functions. This is called **allocation.** Allocation should be based on causal physical relationship (possible when the ratio between quantities of co-products can be changed), on a common representative physical parameter (possible when co-products provide a similar function), or on economic value (consists of using price data on goods and services; if some products have no market, it is possible to calculate a shadow price). Note that the economic value approach is widely used in practice.

Figure 10: *ISO hierarchy for solving multifunctionality in a tree's decision*



Source: Bjorn & al. (2018, p. 90)

2.2.2 Planning and data collect

The collection of data is based on the scope definition and processes identified within the system boundaries. Planning and collection of data are iterative processes. The iterative process may guide the practitioner about which data are relevant to focus on in a second iteration. The starting point for data collection is to create a table that outlines a plan for the data collection for each process (A, B, C, etc.). The structure of the table can follow life cycle stages of the product (Wenzel, Hauschild, Alting, 1997).

The initial planning should be based on the requirements to data representativeness from the scope definition, as well as on the efforts that are expected in order to obtain data of a given quality. Data quality may be classified into one of the five following categories (very high, high, medium, low, very low). The efforts required to obtain data of a given quality can be estimated for each data point (flow quantity) by considering three additional dimensions of the data: (1) data type, (2) data source, and (3) data access.

Figure 11: *Template for planning and collection data*

Process or single data point	Specificity					Type	Source	Access
	Very high	High	Medium	Low	Very low			
X	X					Concentration	Process engineer	Questionnaire
Y		X				Kg/year	Academic paper	Online search
Z				X		Unit process	ecoinvent	Database search

Source: Bjorn, et al. (2018), Wenzel, et al. (1997)

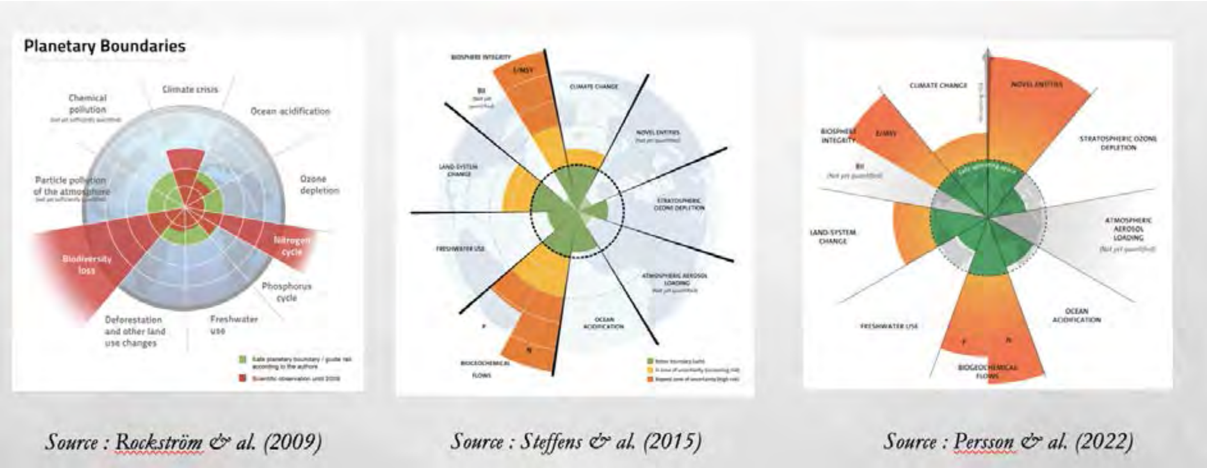
2.3 Impact Assessment (Life Cycle Sustainability Assessment, LCSA)

The impact assessment consists of five elements of which the first three are mandatory according to the ISO 14040 standard (Hauschild et al., 2018):

1. *Selection of impact categories* representative of the assessment parameters (scope definition). For each category, one or two indicators are chosen with an environmental model that can be used to quantify the impact of elementary flows on the indicator.
2. *Classification of elementary flows* from the inventory by assigning them to impact categories according to their ability to contribute by impacting the chosen indicators.
3. *Characterisation* using the environmental model for the impact category to quantify the ability of each of the assigned elementary flows to impact indicators of the category. The results of impact scores are expressed in a common metric for the impact category.
4. *Normalization* is used to inform about the relative magnitude of each of the characterized scores for the different impact categories by expressing them relative to a common set of reference impacts.
5. *Grouping or weighting supports comparison* across the impact categories by ranking them or using weighting factors according to their perceived severity.

More broadly, impact assessment is mapping the sustainable dimensions of LCA. Sustainable development is usually understood in the light of the Brundtland Commission's report "Our common future", through four dimensions: welfare, inter-generational equity, intra-generational equity and interspecies equity (Moltensen, Bjorn, 2018). However, research on environmental footprint (Rees, 1992) and planet boundaries (Rockström et al., 2009; Steffen, et al., 2015; Persson et al., 2022) illustrated the concept of thresholds and limits in relation to an ecosystem's response to increasing human pressure.

Figure 12: *Planetary Boundaries from 2009 to 2022*



Source: Rockström (2009), Steffen (2015), Persson (2022)

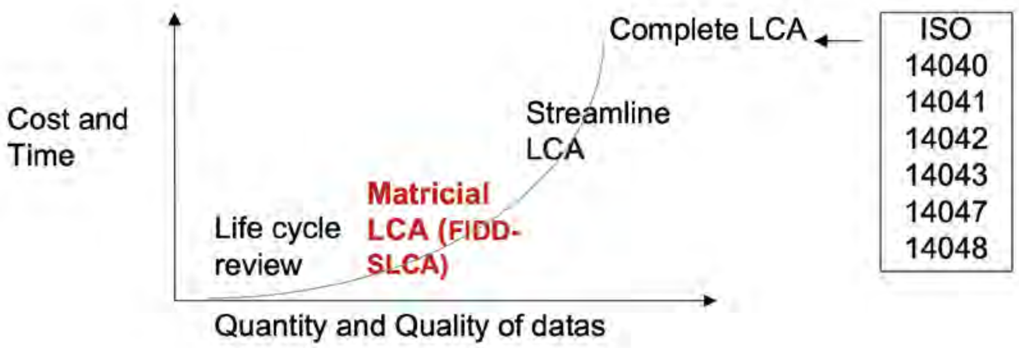
A life cycle perspective is as relevant as it is for the environmental dimension and in a life cycle sustainability assessment (LCSA). To grasp all the dimensions of sustainability, Kloepffer (2008) proposed the following scheme for LCSA.

$$LCSA = ELCA + LCC + SLCA$$

This task may be addressed through an environmental LCA (ELCA), a social LCA (SLCA), a Life Cycle Costing analysis (LCC) (we can add here a Cost-Benefit Analysis (CBA).

Both of these assessment techniques (Jorgensen et al., 2008) have their own distinct methodological foundation (Meyer et al., 2016, Weidema, 2006) which shares the fundamental framework of ELCA but has distinct elements in all phases (Bojorquez-Taîz et al., 2005, Wur et al., 2014). There is also a complex level of different types of LCA (Méthot, 2005).

Figure 13: *Complexity level of different types of LCA*



Source: Méthot (2005, p. 8)

2.3.1 Assessment of Environmental dimension (ELCA)

Performing comprehensive ELCA solutions and comparing them with conventional alternatives, accounting for the complexity of the materials (incl. potential recyclability of end-of-life components) and criteria for technical performance (e.g., impact on the durability of materials) is an ambitious challenge. The ELCA follows a cradle-to-gate framework and is usually focused on the following environmental impact categories: GHG emissions (carbon footprint, in particular biogenic carbon), primary energy demand (energy footprint), water use and consumption (water footprint), land use, as well as impacts on human health and biodiversity. Results may be used in an iterative approach (point 3.) to (i) guide the development of the investigated value chains towards more sustainable solutions, ii) quantify the potential benefits of a solution compared to alternative technologies (baseline), and (iii) help future suppliers and customers make more informed decisions.

2.3.2 Assessment of Social dimension (Social Life Cycle Assessment, SLCA)

Assessment of social dimension introduces two components: the method (Social Life Cycle Assessment, SLCA) to catch social impacts of innovations and leverage points (potential issues for social acceptance) to implement in a better way the innovation.

SLCA is a social impact assessment method (Macombe et al. 2011) that aims to assess the social aspects of products and their positive and negative impacts along their life cycle encompassing extraction and processing of raw materials, manufacturing, distribution, use, reuse, maintenance, recycling, and final disposal (Petti et al., 2016).

We define social aspects as all parameters, indicators, or issues related to the social relations between individuals and between individuals and society (Diemer, 2019), and we apply social aspect classifications established in the Social Life Cycle Assessment (SLCA) methodology (Van Schooten et al. (2003), Weidema (2006), Jorgensen et al. (2008), Dempsey et al. (2011), and Ellen McArthur Foundation (2015)).

The 2000s produced a lot of studies about SLCA, including a multitude of impacts (ranging from direct impacts on workers to broad societal issues), several types of decisions makers and the question of data access (Earthster, 2007; Nazarkina and Le Bocq, 2006; Methot, 2005; Schmit et al., 2004, Caneque, 2002…). So, a lot of methodologies have been developed without a specified target group of users (Flysjö, 2006, Weidema, 2006, Van Schooten, 2003). For example, Van Schooten et al. (2003) and Weidema (2006) treated each social aspect of SLCA according its position on the impact pathways or in the different damage categories :

- Some aspects are inventory items (hours of child labour)
- Some aspects are midpoint indicators (the resulting of lost education)
- Some aspects are damages to instrumental values (lost income)
- Some aspects are damages to intrinsic values (autonomy, language).

The damage categories under the general heading of human life and well-being have been described with proposals for indicators, units of measurement,and a first estimate of global normalisation values. The damage categories are identified as the different aspects of human life that has intrinsic value : Life and longevity, health, autonomy, safety, security and tranquility, equal opportunities, participation and influence (Weidema, 2006). Here, life and longevity are intimately connected. Changes in the expected length of life are measured by the damage indicator Years of Life Lost (YLL).

Jorgensen, Le Boc, Nazarkina and Hauschild (2008) proposed to review all this literature by analysing the existing methodology and proposals for SLCA. The purpose was "*to highlight the general points of agreement and disagreement among the authors and to give a specific focus on the methodological shortcomings* " (2008, p. 97). The interesting issues of the paper are that (1) the authors followed the propositions of UNEP-SETAC and ISO 14040, mainly the three phases (Goal and Scope, inventory analysis and impact assessment) and (2) a parallel has been suggested to methodological discussions, such as Cost Benefit Analysis (CBA), Social Impact Assessment (SIA), Social Accounting (SA) and others.

The objective of the scope definition is to identify the object of the study and delimit the assessment. As ELCA, SLCA identified two main goals : (1) ***One is product, process and company comparison***, with examples from label products and Social Responsible Investments (SRI). **(2) *The other class is identification of product or process improvement potentials which are more* complementary issues.**

Schmidt et al. (2004) introduced Eco and Socio-efficiency as key strategies for managing sustainability of products and processes for the company BASF. The principles of eco-efficiency and social-efficiency make reference to the company scale (gate to gate approach) and the life cycle management of products and processes (cradle to grave approach). The ecological and social impacts that occur throughout the entire product life cycle are put in relation to the costs for the end customer for buying, using, maintaining and finally disposing or reselling the product (total costs of ownership).

$$\text{Eco-efficiency}_{\text{(product/process)}} = \frac{\text{environmental performance throughout the entire product life-cycle}}{\text{total costs of ownership [EUR]}}$$

$$\text{Socio-efficiency}_{\text{(product/process)}} = \frac{\text{social benefit throughout the entire product life-cycle}}{\text{total costs of ownership [EUR]}}$$

According to these equations, "*eco-efficiency and socio-efficiency of products or processes can be improved either by enhancing their ecological and social performance or by reducing the total costs of ownership* " (Schmidt et al., 2004, p. 4). To evaluate social criteria for products and processes and define major areas for social life cycle assessment, the authors used the four capital approach (social capital, human capital, physical capital and natural capital) of the World Bank and the conceptual framework of social indicators from Berger-Schmitt and Noll (2000).

Figure 14: *Four Capital Approach and Major areas for social life cycle assessment*

Types of societal capital	Covered within the SEEbalance® by
Social capital (social networks, associations, and institutions tied by common norms and trustful relationship)	Social LCA
Human capital (people's productive capacities based on skills, education and health)	Social LCA
Produced/physical capital (the stock of machinery, factories, buildings and infrastructure)	Social LCA
Natural capital (the stock of environmental assets such as land, water, wood, flora and fauna)	Ecological LCA

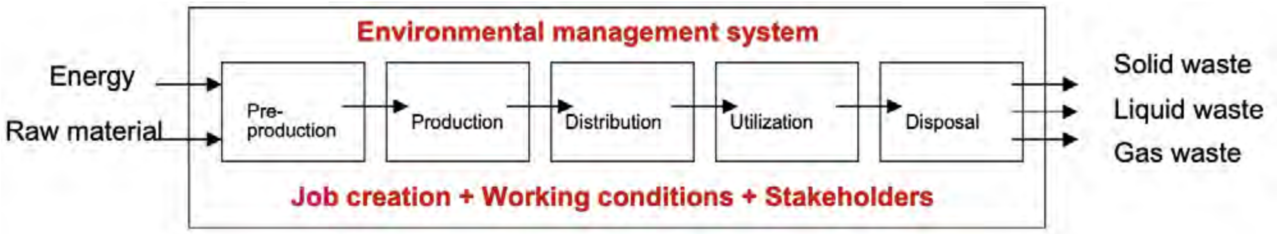
LCA = Life-cycle assessment

Area	Societal capital
1. Human health (prevention of accidents and diseases)	Human capital
2. Nutrition (safeguarding sufficient supply of healthy foodstuffs)	Human capital
3. Living conditions (safeguarding decent living conditions and infrastructure)	Produced capital
4. Education and research (promotion of education, vocational training and R&D)	Human capital
5. Work and working conditions (e.g. job creation, compliance with international labour standards, sufficient payment)	Social capital
6. Further aspects of corporate social responsibility (CSR) (e.g. fair trade with developing countries, product stewardship)	Social capital

Source: Schmidt et al. (2004, p. 7-8)

Méthot (2005) proposed to link LCA and green investment. The Sustainable Development Investment Fund (SDIF) is a responsible investor who is investing in proactive, environmentally and socially responsible companies. The SDIF analyzes investment requests with sustainable development standards through the SDIF-SLCA. It takes into account each stage of the life cycle of a product or a technology (research-development, prototype, production, distribution…) by focusing on the activity of the company. For the dimension of social key drivers, SLCA-SDIF has been adapted to include the experience of Quebec's labor sponsored investment funds with respect to social responsibility (Bouchard, Rondeau, 2003, Kumar, Murray, 2002), the expertise of the CIRAIG about Life Cycle Assessment, reports and documentation from the Health, Safety and Working Conditions Committee (CSST in french) and other tools developed by the Global Reporting Initiative (GRI). Environmental criteria (environmental management system, energy, waste management, resource use) are connected with social criteria (job creation, working conditions, stakeholders relations) at each stage of life cycle (diagnostics, investment conditions, sustainable development committee, reassessment).

Figure 15: *Environmental and Social criteria*

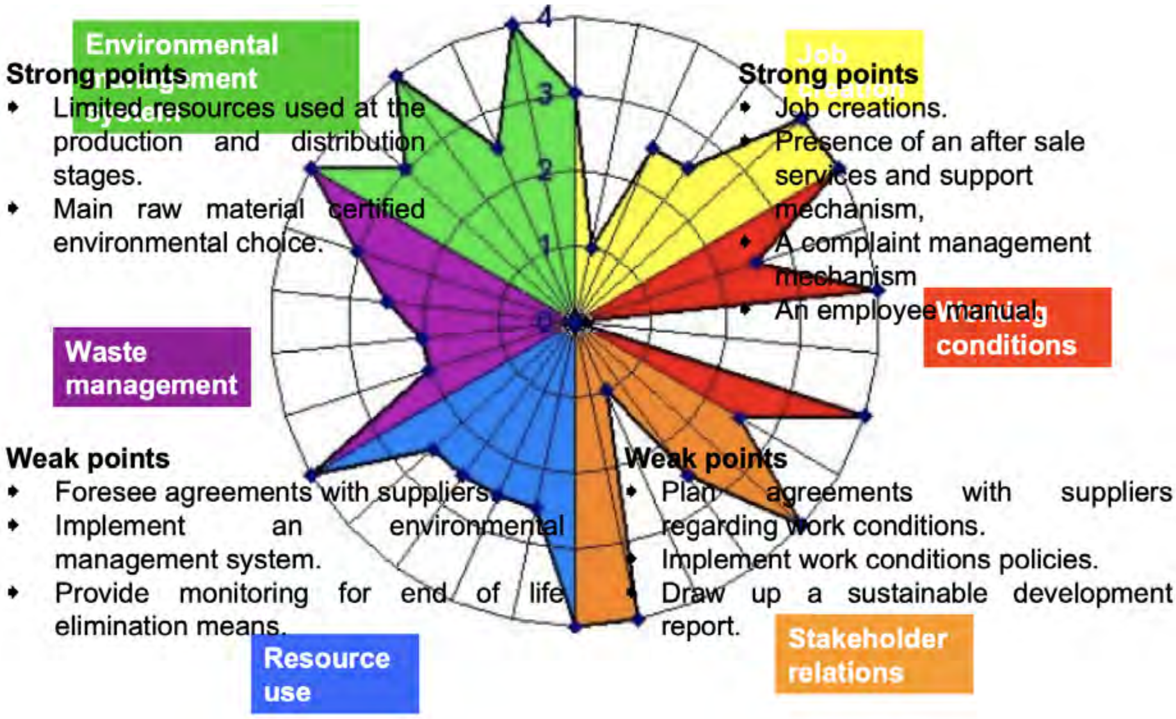


Source: Méthot (2005, p. 12)

At the diagnostics stage, strengths and weaknesses are identified by an external auditor using the SLCA-SDIF.

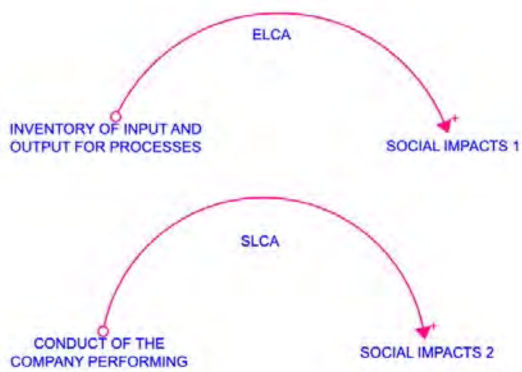
To identify the origin of social impacts, there is some difference between ELCA and SLCA. ELCA accepts the proposal that there is a causal link between process and environmental impact (environmental impacts rise because of the nature of the processes). So, environmental impacts are the aggregated inventory of input and output for processes (Jorgensen & al., 2008). Regarding SLCA, Dreyer & al. (2006) and Spillmaeckers, et al. (2004) argued that most social impacts have no relation to the processes themselves, but rather to the conduct of the companies performing the processes (see the part on economic assessment). Therefore, the causal link is from the conduct of the company to the social impact.

Figure 16: *Environmental and social impacts at the diagnostics stage*



Source: Méthot (2005, p. 14)

Figure 17: *The causal link of ELCA and SLCA*



If scope definition (origin of social impacts, method of allocation in SLCA, etc.) and systems boundaries are useful to focus on these parts of the life cycle assessment that companies may influence directly to perform their results, social indicators and impact categories give an overview of the practices. The indicator type gives information on the quantitative (measurements in physical units, semi-quantitative scoring, etc.) and qualitative description (Norris, 200§, Wedeima, 2006), covert endpoint (targets), and midpoints (pathways) indicators. This last difference is crucial in the SLCA scenario. For example, job creation is normally not considered as a goal in itself; firms firstly maximize profits and supply chain value, job creation is the consequence of this motivation. When firms distribute

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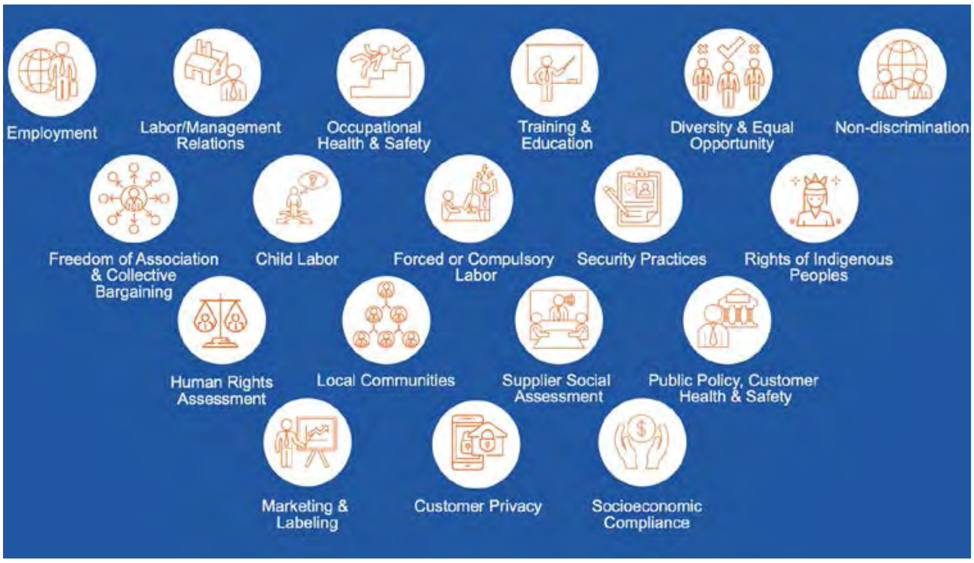
salaries to people, these incomes may reduce poverty and improve health conditions and life quality. Thus, job creation is a midpoint indicator and the improvement of life quality is the endpoint indicator. The link between job creation and life quality has to be described inside an impact pathway describing the causal effect and consequence effect relationships between midpoint and endpoint indicators (we will develop this systemic approach in point 3. *Iterative nature of LSCA by using causal loop diagrams*). If endpoint indicators have the advantage of reflecting the potential damage or benefit to the valued item or industrial process (Jorgensen, et al., 2008), SLCA approaches using midpoint indicators offer a great variety of issues and pathways. They use a social matrix developed by EU Reporting (2000), the Global Reporting Initiative (2007), or a technical report published by JRC (2015). The EU Reporting (2000) presented a conceptual framework and structure of a European System of Social Indicators. This report made some efforts to monitor and systematically describe the current state of and change in living conditions and the quality of life (see Figure 18). The process of European integration has obviously stimulated the development of such monitoring and reporting activities. Concepts of welfare (e.g., quality of life concepts, concepts of the quality of societies, livability, social cohesion, social exclusion, social capital, sustainability, human development, social quality) and goals of societal development (promotion of employment, the enhancement of education, the improvement of public health, the reduction of regional disparities, equal opportunities of women and men, solidarity, etc.) are the elements of the conceptual framework.

Figure 18: *Conceptual framework of the european system of social indicators*

Source: Berger-Schmitt, Noll (2000, p. 43)

The Global Reporting Initiative (2007) developed a flexible framework for reporting (Figure 19). The GRI Standards are structured as a set of interrelated standards. There are three universal standards that apply to every organization preparing a sustainability report. An organization selects from the set of topic-specific GRI standards for reporting on its material topics. The topic-specific GRI standards are organized into three series: 200 (economic topics), 300 (environmental topics), and 400 (social topics). The economic dimension of sustainability concerns an organization's impacts on the economic conditions of its stakeholders and on economic systems at local, national, and global levels. It does not focus on the financial condition of an organization. The environmental dimension of sustainability concerns an organization's impacts on living and non-living natural systems, including land, air, water, and ecosystems. The social dimension of sustainability concerns an organization's impacts on the social systems within which it operates. Social dimension includes employment, labor/management relations, occupational health and safety, training and education, child labor, security practices, human rights assessment, local communities, marketing and labeling, customer privacy, etc.

Figure 19: *Social dimension in the Global Reporting Initiative*



Source : GRI (2007, p. 11)

Finally, JRC technical reports (2015) compared LCA and SCLA to challenge the level of methodological development, application, and harmonisation. A schematic methodological approach of SCLA has been proposed (see Figure 20). The basic step of an LCA can also be adopted in SCLA, namely: (1) defining goal and scope of the assessment, (2) inventory of the drivers which may lead to an impact, (3) impact assessment based on the selection and calculation of proper indicators of impacts, and (4) interpretation of the results.

Figure 20: *Schematic methodological approach of SLCA*

Source: JRC (2015, p. 2)

However JRC considered that SCLA was still at the preliminary stage. That is why they proposed to present (1) the state of the art in social Life Cycle Assessment, illustrating the main theoretical and methodological elements under scientific literature; (2) the overlaps and the synergies with traditional LCA, towards a common and integrated assessment framework; and (3) examples of applications of SLCA at macro scale (EU - 28) and at sector scale. The JRC report insisted on databases and indicators for SLCA. Data sources for implementing social impact assessment are crucial and in many cases very difficult to be built and maintained. Two relevant databases are described: the social hotspots Database (SHDB), including a global input-output model, a worker hours model and data on social risks and opportunities, and the Product Social Impact Life Cycle Assessment Database (PSILCA). PSILCA is a database showing how social data can be organized, assessed and finally used for SLCA or Life Cycle Sustainability Assessment (see Figure 21). The database is planned to contain the indicators for 187 countries and avoreall for 15909 sectors.

Figure 21: *List of social indicators for PSILCA*

STAKEHOLDER	SUBCATEGORY	INDICATOR	Unit of measurement
WORKERS	CHILD LABOUR	Children in employment, male (% of male children ages 7-14)	%
		Children in employment, female (% of female children ages 7-14)	%
		Children in employment, total (% of all children agess 7-14)	%
	FORCED LABOUR	Evidence of forced labour	Text
		Frequency of forced labour	%
	FAIR SALARY	Living wage, per month	local currency
		Minimum wage, per month	local currency
		Sector average wage, per month	local currency
	WORKING TIME	Hours of work per employee, per day	h
		Hours of work per employee, per week	h
		Standard weekly hours	h
		Standard daily hours	h
	DISCRIMINATION	Occurrence of discrimination	Text
		Women in the labour force (% of economically active female population)	%
		Men in the labour force (% of economically active male population)	%
		Ratio of salary of women wages to men	%
	HEALTH AND SAFETY	Accident rate at workplace	#/100,000 workers
		Fatal accidents at workplace	#/100,000 workers
		Occupational risks	Text
		DALY due to indoor and outdoor air and water pollution	DALY/1,000 persons
		Presence of sufficient safety measures	# of security incidents
	SOCIAL BENEFITS, LEGAL ISSUES	Social security expenditures out of the total GDP	%
		Evidence of violations of laws and employment regulations	#/yr h
		% of workers with a contract	%
	FREEDOM OF ASSOCIATION, COLLECTIVE BARGAINING, RIGHT TO STRIKE	Trade union density (% of employees organised in trade unions)	%
		Right of association	index value
		Rigth of collective bargaining	index value
		Right to strike	index value
		Existence of standard rates	Y/N
LOCAL COMMUNITY	ACCESS TO MATERIAL RESOURCES	Level of industrial water use (% of total withdrawal)	%
		Level of industrial water use (% of total actual renewable)	%
		Extraction of material resources (fossil fuels, biomass, ores, minerals)	t/capita
		Presence of certified environmental management systems	#
		Description of (potential) material resource conflicts	Text
	RESPECT OF INDIGENOUS RIGHTS	Presence of indigenous population	Y/N
		Human rights issues faced by indigenous people	Text
		Respect of indigenous rights	Text
	SAFE AND HEALTHY LIVING CONDITIONS	Pollution level of the country	Index value
		Contribution of the sector to environmental load	Text
		Drinking water coverage (% of the population)	%
		Sanitation coverage (% of the population)	%
	LOCAL EMPLOYMENT	Unemployment rate in the country	%
		Work force hired locally	%
		Percentage of spending on locally based suppliers	%
	MIGRATION	Migrant workers in the sector	%
SOCIETY	CONTRIBUTION TO ECONOMIC DEVELOPMENT	Economic situation of the country	index value
		Contribution of the sector to economic development (in % of total GDP)	%
	EDUCATION	Public expenditure on education (% of GDP)	%
		Illiteracy rate, male (% of male population)	%
		Illiteracy rate, female (% of female population)	%
		Illiteracy rate, total (% of total population)	%
	HEALTH AND SAFETY	Health expenditure out of the total GDP of the country	%
		People affected by natural disasters (as % of population)	%
		Life expectancy at birth	Years
	PREVENTION AND MITIGATION OF CONFLICTS	Risk of conflicts with regard to the sector	Text
VALUE CHAIN ACTORS	FAIR COMPETITION	Presence of anti-competitive behaviour or violation of anti-trust and monopoly legislation	Text
		Presence of policies to prevent anti-competitive behaviour	Y/N
	CORRUPTION	Corruption index of country	index value
		Evidence of an active involvement of the enterprises in corruption and bribery	%
	PROMOTING SOCIAL RESPONSIBILITY	Presence of codes of conduct that protect human rights of workers among suppliers	index value
		Membership in an initiative that promotes social responsibility along the supply chain (number of enterprises)	#
	SUPPLIER RELATIONSHIPS	Interaction of the companies with suppliers (payment on time, sufficient lead time, reasonable volume fluctuations, appropriate communication...)	Text
CONSUMERS	HEALTH AND SAFETY	Presence of management measures to assess consumer health and safety	Y/N
	TRANSPARENCY	Presence of certifications or labels for the product/sites sector	Y/N
	END OF LIFE RESPONSIBILITY	Strength of national legislation covering product disposal and recycling	Text

Source: JRC (2015, p. 44)

Many SLCA case studies have decided to focus on categories such as human rights, discrimination and physical working conditions, labour practices, society issues, and so on (Figure 22). Therefore, they reduce the original complexity of social impacts and define the order of priority of all organizations. For example, social conflicts are defined at the organization level and not at the individual level, so social conflicts between workers and managers are not considered. Midpoint indicators has two advantages: (1) they are part of a scenario, a pathway to reach an objective (so they give more information about the gap between estimated target and real target) and (2) their value may be negative (scoring), as some indicator (reduce the poverty of the workers) may just be acceptable, but not really good (social progress is slow and complex).

Figure 22: *Impact categories and indicators*

Impact categories	**Number of indicators, quantitative/descriptive (q/d):**											
	Barthel et al.	**Cañeque**	**Dreyer et al.[1]**	**Flysjö[2]**	**Gauthier**	**Hunkeler**	**Manhart & Grießhammer**	**Méthot[3]**	**Nazarkina & Le Bocq[4]**	**Schmidt et al.**	**Spillemaeckers[5]**	**Included in approaches**
Human rights												
Non-discrimination, including indicators on diversity, such as composition of employees on all levels according to gender, age group, disabled, part-time workers and other measures of diversity	2,q	10,q	1,q	3,q	1,d		1,d	?,q	4,q	5,q	2,q	10
Freedom of association and collective bargaining	2,q		1,q	1,d			1,d	?,q	1,q	1,q	8,q	8
Child labour, including hazardous child labour	2,q		1,q	1,d			1,d		1,q	1,q	3,q	7
Forced and compulsory labour	1,q		1,q	1,d			1,d		1,q	1,q	3,q	7
Labour practices and decent work conditions												
Wages, including equal remuneration on diverse groups, regular payment, length and seasonality of work and minimum wages	1,q	3,q		6,q 1,d			2,d	?,q	4,q	1,q	5,q	8
Benefits, including family support for basic commodities and workforce facilities				1,d		1,q	1,d		6,q	4,q		5
Physical working conditions, including rates of injury and fatalities, nuisances, basal facilities and distance to workplace	2,q	2,q	1,q	2,q 3,d	1,d		1,d	?,q	4,q	6,q	9,q	10
Psychological and organisational working conditions, such as maximum work hours, harassments, vertical, two-way communication channels, health and safety committee, job satisfaction, and worker contracts				1,d	1,d		2,d		10,q	1,q	8,q	6
Training and education of employees		2,q		2,d	1,d		1,d	?,q	6,q	1,q	2,q	8
Society												
Corruption, including incidents/press reports concerning fraud, corruption and illegal price-fixing, and violation of property rights.					1,d		2,d		2,q	1,q		4
Development support and positive actions towards society, including job creation, support of local suppliers, general support of developing countries, investments in research and development, infrastructure, and local community education programmes	6,q			1,q			12,d	?,q	12,q	8,q	5,q	7
Local community acceptance, such as complaints from society, and presence of communication channels					1,d			?,q	4,q	1,q	5,q	5
Ensuring of commitment to sustainability issues from and towards business partners							2,d				6,q	2
Product responsibility												
Integration of costumer health and safety concerns in product, such as content of contaminants/nutrients, other threats/benefits to human health (including special groups) due to product use, and complaint handling system				2,q	1,d					5,d	1,q	4
Information about product to users, such as labelling, information about ingredients, origin, use, potential dangers, and side effects.										1,q 2,d	2,q	2
Marketing communications, such as ethical guidelines for advertisements										1,d		1

Impact categories	Number of indicators, quantitative/descriptive (q/d)	
	Norris	Weidema[6]
Mortality	1,q	?
Morbidity	1,q	?
Autonomy		15?,q
Safety, security and tranquillity		6?,q
Unequal opportunities		?
Participation and influence		?

The numbers, d, and q in Table 1 and 2 refer to the number of indicators included on the given impact category, and whether the indicators are descriptive (qualitative) or quantitative

Source: Jorgensen et al. (2008)

Regarding the impact on the consumer in the use stage, few impact categories are suggested (e.g., information about products, labels, ingredients), but Dreyer, et al. (2006) consider that potential social impacts in the final stage are different and variable from the products themselves. Furthermore, the use stage is connected with the definition of functional unit, the function of the product or service (both in quantity and quality), and the choices of consumers. SLCA constitutes a viable screening tool that can pinpoint environmental and social hotspots (Hellweg, Mila, 2014) in complex value chains. Fidan, Avdogan, Uzal (2022) used the LCA approach to challenge the impact of organic cotton use and consumer habits in the sustainability of jean production. They showed that all of the selected environmental impacts of a pair of jeans are reduced in all scenarios when organic cotton is used. Additionally, consumer habits had a significant impact on all impact categories.

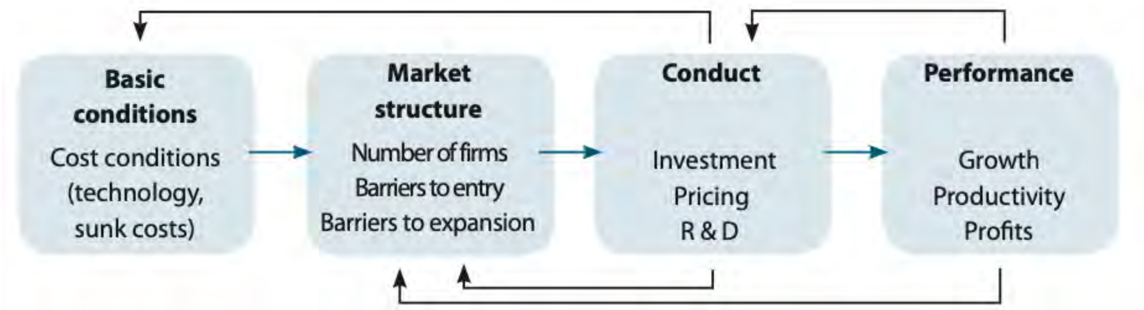
For companies, this framework has the advantage to investigate the innovation process in light of SLCA (Social Life Cycle Assessment) and LCSA (Life Cycle Sustainability Assessment) indicators connected to Sustainable Development Goals (SDGs also have indicators). The analysis is informed by the following empirical methods. At micro-level, a social dashboard has to be built for all the partners to highlight midpoints indicators and endpoints indicators. The gap between midpoint and endpoint indicators will be useful to challenge pathways. At the meso and macro level, the challenge is the social acceptance of innovation.

2.3.3 Assessment of economic dimension

The Life Cycle Costing (LCC) forms the economic pillar in a full life cycle sustainability assessment comprising the environmental, economic, and social dimensions (Moltesen, Bjorn, 2018), but the LCC is not to challenge the economic dimension of LCA. Cost-Benefit Analysis (CBA), Market structure (MS), and firm level economic performance (FLEP) are necessary to support business models, especially in a circular economy oriented innovation (Blomsma et al., 2019). The R-framework (from 4R to 10R) has the advantage to map the different circular economy strategies (Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, and Recovery) and to foresee how they influence the performance and the resilience of the supply chain (Kirrchherr et al., 2017). The economic dimension of LCA introduces three spatial scales (macro, meso, and micro).

The macro level introduces the market structure and sectoral indicators. The literature in economics is related to cross industry studies in the tradition of the SCP (Structure, Conduct, Performance) tradition (Holzl, Reinstaller, 2009). The SCP model holds that the structure of an industry (number of firms, concentration, etc.) determines the way in which firms compete (conduct), and this in turn determines their performance (profitability). This deterministic version has been improved to take account of feedback links between conduct, market structure, and performance (Diemer, 2016). The assessment of the economic dimension is quite connected to the modified structure - Conduct - Performance model. Cost conditions (wages, cost of external capital, fixed entry costs, sunken costs), technology, demand conditions, and state regulation are part of the basic conditions. Market Structure includes the number of firms, barriers to entry, barriers to expansion, share of market, economies of scale, new entrant, and uncertainty. Conduct is influenced by investments, research and development expenditures, pricing, and margins. Sectoral Performance is concerned by the growth of the market, productivity of labour and capital and profits.

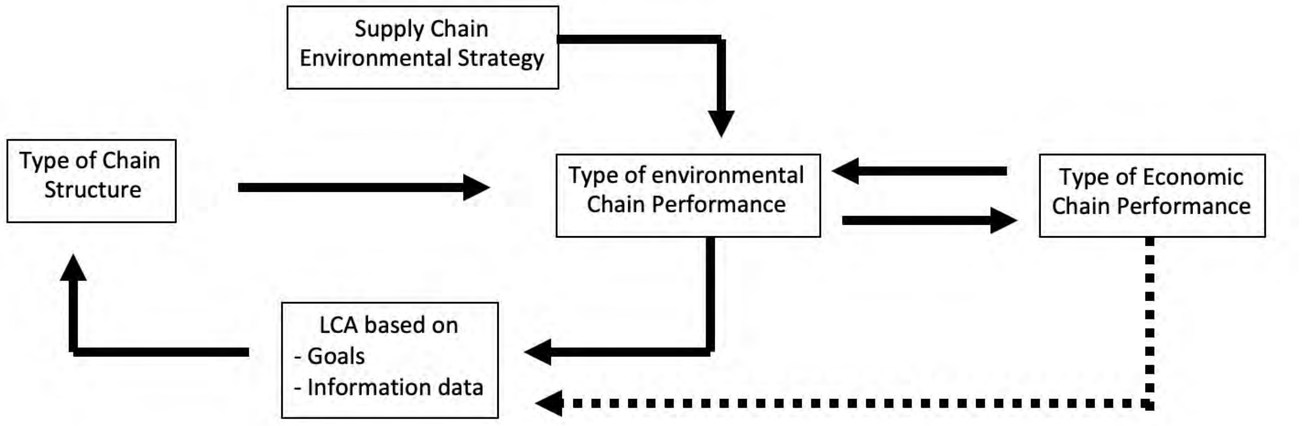
Figure 23: *Market structure and sectoral performance*



Source: Holzl, Reinstaller (2009)

The meso level is more concerned with the structure and the type of supply chain. Here, we define the supply chain as a chain co-operation, this is "*the integration of business processes from consumer to the original suppliers leading to product-service information that has added value to customers*" (Cooper, Lambert & Pagh, 1997). Indeed, LCA becomes a context-dependent tool. Actors within a supply chain pursue a certain environmental strategy. When all the actors agree on that strategy, they define an Environmental Supply Chain Management Strategy (ESCMS). Zsidisin & Siferd (2001) define ESCM as "*the set of supply chain management policies held, actions taken, and relationships formed in response to concerns related to the natural environment with regard to the design, acquisition, production, distribution, use,reuse, and disposal of the firm's goods and services*". LCA may be seen as the main instrument of ESCMS. It becomes a technique for gathering data and information on environmental issues, which can be used to restructure the supply chain in order to improve environmental and economic performance. Indeed, when a supply chain strives to realize specific performance objectives (environmental and economic), one specific supply chain structure becomes more suitable than the other (Hagelaar, Van Der Vorst, 2002). In that case, economic assessment is subject to the objectives of environmental assessment (economic assessment and environmental assessment are connected by a feedback loop). The aim is to reduce the environmental impact of a process without compromising economic performance indicators. Many questions lead to the problem statement: What LCA data is required to conduct ESCMS? What types of environmental performance objectives can be designed? Are they compatible with the economic performance objectives? What supply chain is the most appropriate for reaching those objectives? What are the critical success factors for partnerships?

Figure 24: *Framework of ESCMS*



Source: The Author

Cooper & Gardner (1993), Zuurbier, Trienekens & Ziggers (1996), Simpsons & Long (1998), Lambert, Cooper & Pagh (1998), Hagelaar and Van Der Vorst (2002) provide an overview of aspects mentioned as relevant in determining if a partnership is appropriate (each relationship has its own set of motivating factor driving its development).

Figure 25: *Success Factors for driving the supply chain*

Drivers for partnerships	Main partnership facilitators	Successful partnership characteristics
Asset-cost efficiencies (cost reduction) Customer service (e.g., shorter cycle times) Marketing advantage (e.g., entrance into new markets) Profit stability/growth	Strategic complementarity. Corporate compatibility (culture and business goals) Compatibility of managerial philosophy and techniques. Mutuality (joint objectives, sharing of sensitive information) Symmetry in power.	Joint planning. Global SC operating controls. Systematic operational information exchange (rapid and accurate transfer) Sharing of benefits/burdens. Trust and commitment. Extendedness (the relationship will continue into the future) Corporate culture bridge-building.

Source: Haagelard, Van Der Horst (2002, p. 403)

The meso level is a very interesting level because it introduces the question of the compatibility between environmental assessment and economic assessment inside the supply chain. Hagelaar & Von Der Host (2022), Van Koppen & Hagelaar (1998), Vermaak (1995), Spliethoff & Van Der Kolk (1991) designed a typology of environmental strategies applicable to individual companies and supply chains:

- *Compliance Oriented Strategy (COE)*: Comply with the rules and regulations with the help of end-of-pipes techniques. Example of filters on chimneys to diminish a particular kind of GhG emissions.
- *Process-oriented Strategy (POS)*: Strive for control of the environmental impacts caused by the production process by means of production integrated measures that achieve both compliance with governmental rules and regulation. Example of process oriented measures from new technology to save raw materials or to redesign the process (less materials during the production process).

- *Market-Oriented-Strategy (MOS)*: Aim for the reduction of environmental impacts caused by the design of the product to achieve competitive advantage. At this stage, the R&D department has to incorporate the environmental impacts (eco-design in the circular economy) in the design process.

All these environmental issues are linked in an ideal type strategy that the partners of the supply chain have to design. Strategic choices have to be made concerning environmental and economic assessment. These choices require different organizational capabilities. For compliance-oriented strategy, LCA may be focus on End-of-pipe data (e.g., emissions), for process-oriented strategy, LCA may include End-of-pipe, process steps and transport data, and for market-oriented strategy, LCA could take care of End-of-pipe, process steps, transport, nature and quantity of raw materials, and disposal data.

Figure 26: *Typology of Environmental strategies for supply chain*

Characteristics	Compliance	Process	Market
Internal			
Knowledge	Knowledge about some, prescriptive, aspects	Knowledge about production process aspects	Knowledge about the product supply chain
Information	Little horizontal and vertical information sharing	Information sharing on tactical and operational level	Information sharing on strategic level
Technology	End-of-pipe technology	Process-integrated technology	Product design technology
Structure	Few and isolated tasks	Explicit tasks on the tactical and operational level	Integrated tasks on different levels including staff level
Budget	Budget is small	Budget for investments with a long term pay-back period	Budget for strategic investments
External			
Risks	Risks are deduced from the rules and regulations	Risks are limited and/or changeable	Risks become challenges
Opportunities	No opportunities	Opportunities through cost savings	Market opportunities

Source: Van Koppen, Hagelaar (1998)

The micro level introduces more discussion about the integration of Life Cycle Costing (LCC), Cost-Benefit Analysis (CBA), and Circular Business Model (CBM).

Life Cycle Costing is a technique capable of being applied to a range of purposes and at different stages in the project or asset life cycle to support decision making (Rödger, Kjaer, Pagoropoulos, 2018). Life Cycle Costing of a product can be defined as the sum of all funds expended in support of the product from its conception and fabrication through its operation to the end of its useful life. LCC seeks to optimize the cost of acquiring, owning, and operating physical assets over their useful lives by attempting to identify and quantify all the significant costs involved in that life (White, Ostwald, 1976). The LCC approach identifies all future costs and benefits and reduces them to their present value by the use of the discounting technique (Kloepffer, 2008). It is possible to present a non-exhaustive list of elements of the LCC such as the initial capital costs, the life of the asset, the discount rate, the operating and maintenance costs, the disposal cost, information and feedback, and uncertainty and sensitivity analysis. To facilitate the evaluation, Kaufman (1970) proposed a LCC procedure based on an eight step approach: (1) establish the operating profile OP (description of the periodic cycle through which the equipment will go), (2) establish the utilization factors (indicates in what way equipment will be functioning within each mode of the OP), (3) identify all the cost elements (every cost must be identified), (4) determine the critical cost parameters (time period between failures, time period for repairs, energy use rate, etc.), (5) calculate all costs at current prices, (6) escalate current costs at assumed inflation rates (example of interest rates for physical assets), (7) discount all costs to the base period (money has a time value and the cash flows occurring in different time periods should be discounted back to the base period), and (8) sum discounted costs to establish the net present value. From his part, Harvey (1976) developed a general procedure for LCC analysis in which he identified the cost elements of interest (all the cash flows that occur during the life of the asset), the cost structure (grouping costs to catch potential trade-offs to achieve optimum LCC; it is possible to divide costs in categories: research and development, production and implementation, operation), a cost estimated relation (a mathematical expression that describes the cost of a product as a function of independent variables), and the method of LCC formulation (method to evaluate the assets).

More recently, three variants of the LCC method have been developed. *Conventional LCC* (financial LCC) is the original method. LCC is applied as a decision making tool to support acquisition of capital equipment and long lasting products with high investment costs (Martinez-Sanchez, Kromann, Astrup, 2015). The Convention LCC is useful for a single actor or from the manufacturer's point of view (Hunkeler, Lichtenvort, Rebizer, Ciroth, 2008). In this last case, the life cycle cost breaks down with specific focus on the production stages. *Environmental Life Cycle Costing* (eLCC) is connected with the ISO Standard 14040 and 14044 on LCA. This method takes into account the perspective of a functional unit and the whole life cycle, including all actors of the supply chain or life cycle (Steen, 2015, Hoogmartens & al., 2014)). eLCC has been developed to support LCA in the sense that it covers the economic dimension and helps to identify hot-spots in terms of cost and environmental impacts (Rödger, Kjaer, Pagoropoulos, 2018). Societal LCC (sLLC) is to support decision making on a societal level, including governments and public authorities (CIroth, Hildenbrand, Steen, 2015). Societal assessment is advocated as one of the three pillars in the movement toward sustainability (Hunkeler, 2006). It permits relative product comparisons rather than absolute analysis. Societal LLC includes selected external costs by assigning a monetary value to them. This process is a monetization of costs and impacts. A sLLC goes very far because it monetarizes all environmental and social impacts (job creation, job quality, working conditions, etc.). Societal LCC has some connection with Corporate Social Responsibility (CSR). Societal LCC offers the advantage of presenting results in one single monetary unit, integrating all the three pillars of sustainability, and supporting policy decisions in a combined Life Cycle Sustainability Assessment (Timonen, Harrison, Katajajuuri, Kurppa, 2017). Integrating societal Life Cycle Cost (sLLC) and LCSA removes all pre-existing methodological differences between LLC and LCA. Initially, LCC and LCA were used to answer different questions (Klöpffer, Ciroth, 2011). LCC compares the cost effectiveness of alternative investments or business decisions from the perspective of an economic decision maker (producer or consumer). LCA evaluates the relative environmental performance of alternative product systems for providing the same function (Norris, 2001). This environmental performance considers all important process casualties, resources, and consumption flows regardless of their impact. These differences in their purpose were linked to their differences in their scope and method (see Figure 27).

Cost Benefit Analysis (CBA) is a systematic and analytical process of comparing benefits and costs in evaluating the desirability of a project or a programme. For Quah and Toh (2012), "*CBA is fundamental to government decision-making and can be an effective tool for making informed decisions on the use of society's scarce resources*". In fact, the idea behind CBA is quite simple : if the benefits outweigh the costs, then an action is taken, otherwise it is not. CBA concerns the economy as a whole but also the decision making process supported by profit and loss accounting (which is individual behavior). For companies, profit and loss accounting as a tool, seems more relevant to explain dynamics, consequences and impacts of a decision making process. Firstly, the effects (benefit and cost) of a company's action are not limited to the company itself. Secondly, externalities (environmental and social ones) and transfer payments are not always included in the profit and loss accounting. Thirdly, the benefit and the cost analysis of items is not homogeneous. Most of the time, items are valued at their market prices (monetary prices) in profit and loss accounting, but it's also possible to use their opportunity cost.

Figure 27: *Differences between LCC and LCA*

Tool/Method	LCA	LCC
Purpose	Compare relative environmental performance of alternative product systems for meeting the same end-use function, from a broad, societal perspective	Determine cost-effectiveness of alternative investments and business decisions, from the perspective of an economic decision maker such as a manufacturing firm or a consumer
Activities which are considered part of the 'Life Cycle'	All processes causally connected to the physical life cycle of the product; including the entire pre-usage supply chain; use and the processes supplying use; end-of-life and the processes supplying end-of-life steps	Activities causing direct costs or benefits to the decision maker during the economic life of the investment, as a result of the investment
Flows considered	Pollutants, resources, and inter-process flows of materials and energy	Cost and benefit monetary flows directly impacting decision maker
Units for tracking flows	Primarily mass and energy; occasionally volume, other physical units	Monetary units (e.g., dollars, euro, etc.)
Time treatment and scope	The timing of processes and their release or consumption flows is traditionally ignored; impact assessment may address a fixed time window of impacts (e.g., 100-year time horizon for assessing global warming potentials) but future impacts are generally not discounted	Timing is critical. Present valuing (discounting) of costs and benefits. Specific time horizon scope is adopted, and any costs or benefits occurring outside that scope are ignored

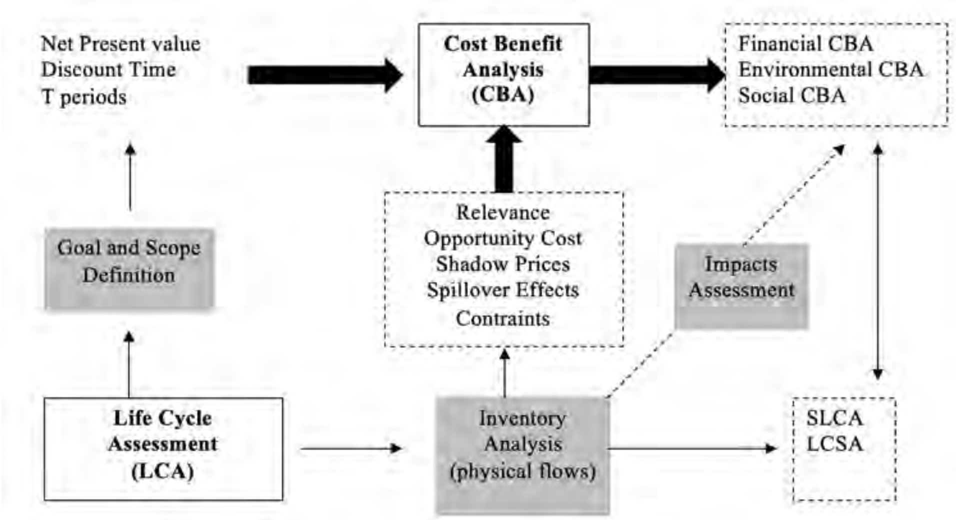
Source: Norris (2001, p. 118)

For Layard and Glaister (1994, p. 3), the valuations to be made in any cost-benefit analysis fall under four main headings : (i) the relative valuation of costs and benefit at the time when they occur; (ii) the relative valuation of costs and benefits occurring at various points in time, this is the problem of time preference and the opportunity cost of capital (Diemer, 2000), (iii) the valuation of risky outcomes and (iv) the valuation of costs and benefits accruing to people with different incomes. For practical reasons, it is usually convenient in any cost-benefit analysis to proceed in two stages. Stage 1 defines the costs and the benefits in each year of the project. Stage 2 proposes an aggregate "present value" of the project by discounting costs and benefits in future years to make them commensurate with present costs and benefits, and then adding them up. The difference between benefit and cost is illustrated by the concept of cash flows (Brent, 2009). In order to obtain the net present value (NPV) of a project (or an item), it is necessary to apply a discount rate (x) to cash flows (CF) across T years.

$$\text{NPV} = \sum_{t=1}^{T} \frac{\text{CF}_t}{(1+x)^{t-1}}$$

Some of the principles of CBA were highlighted in many books and articles (Robinson, 1993, Layard, Glaister, 1994, Qua and Toh, 2012) : relevance, shadow prices, spillover effects or constraints. For benefit and loss accounting, relevance is concerned with the inclusion and exclusion of items. This stage depends on the limits of the project. Shadow prices are the true valuation of the item. The market prices (monetary) are subject to many distortions (taxation and subsidies for example). The goal is to adjust prices to correct these distortions. Spillover effects are an extension of shadow prices. Some items have spillover effects (externalities) that cause social and environmental impacts on value. Some goods produce damages to Nature and human health, these spillover effects should be included in the CBA. In the literature, all these principles introduced different CBA types (Hoogmartens & al., 2014) as financial CBA (profitability assessment), environmental CBA (external costs to express the damage in monetary value) or social CBA (focus on welfare, job creation, education benefits…). The connection between CBA and LCA is an important key to full sustainability assessments but the challenge is significant (Manzo, Salling, 2016). On the one hand, the CBA focuses on the notion of profitability. This financial goal can quickly come into conflict with LCA's sustainability objectives. On the other hand, LCA has the advantage of proposing an inventory of flows and stocks, which can prove useful when it comes to identifying all the impacts of a company's activities (products) and or clarifying the outlines of the main principles of CBA and CBA (figure 28).

Figure 28 : Connections between CBA and LCA



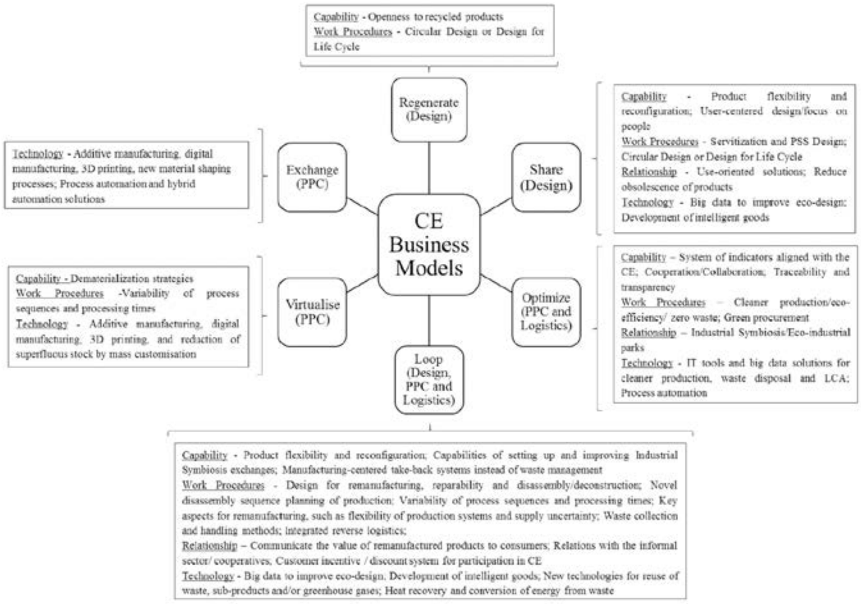
Source : The author

LCA may improve CBA's methodology in two directions : (i) LCA extracts from the life-cycle inventory, the information related to direct and indirect environmental impacts. This extraction is expressed in physical quantities. (ii) LCA translates these physical quantities in monetary terms, using them as reference values for CBA.

Circular Business Model is part of the literature developing a terminology and a framework for companies' strategies (Bocken & al., 2015). The circular economy approach contrasts with the traditional linear model of production. The recent framework based on 10 common circular economy strategies (rethink, repurpose, refuse, recover, remanufacture, refurbish, repair, re-use, reduce, recycle) is usually applied to challenge different selected targets (Morseleto, 2020). All these strategies address issues related to the way products are designed (eco-design), produced (manufacturing, cooperation, organization, industrial metabolism, stocks and flows), used (sustainable consumption, zero waste, economy of functionality) or recycled. It's a long process that questions our vision of profitability, our relationship with others and our place on the planet. While many companies are trying to integrate the 4 Ps (Profit, People, Planet, Partnership) of sustainability into their business models, few are yet able to translate this sustainability into circularity. The integration of environmental and social impacts into strategic choices is a reality, but this choice must not jeopardize efficiency and profitability. Companies are still high places where profit is made, and it still seems difficult to move from a profit-oriented economy to a sustainable one. Profit (value creation) is still the goal, and rarely the means to more noble ends. The question of circularity, and more broadly that of Circular Business Models, cannot be separated from this analytical framework. For example, Linder and Willliander (2016, p. 2) define a circular business model as "*a business model in which the conceptual logic for value creation is based on* *utilizing the economic value retained in products after use in the production of new offerings"*. From that definition, the Business Model concept provides a framework for understanding how companies define, create and capture value while applying the principles and the practices of circular economy (Ludeke-Freud & al., 2018, Ferasso & al., 2020).

At the same time, circularity raises questions about the limits of the industrial system, its ability to integrate global issues (climate, pollution, health..), to identify all the interactions and feedbacks of induced changes (technological processes) and to identify main pillars of sustainability (Efficiency, circularity, resilience, cooperation, proximity…). Lewandowski (2016) proposes an overview of the circular business models, systematized according to the ReSOLVE framework (Regenerate, Share, Optimize, Loop, Virtualize, Exchange). Lopes de Sousa Jabbour & al. (2019) used this framework to illustrate the most influential decisions (operations management decisions m aking) for each circular economy business model (figure 29).

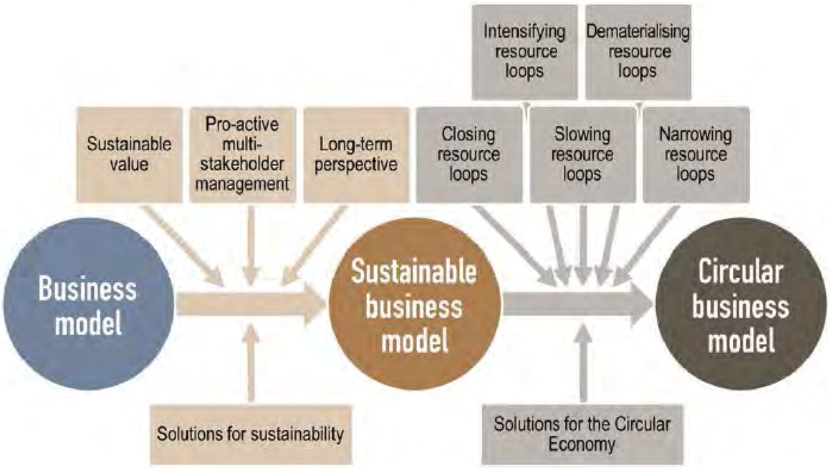
Figure 29 : Circular Business models and operations management decisions making.



Source : Lopes de Sousa Jabbour & al. (2019, p. 1533).

For their part, Urbinati & al. (2017) assume that the degree of circularity of companies from a business model perspective may be explained by the two major dimensions : (i) the customer value proposition & interface (defining the implementation of the circularity concept in proposing value to customers and the positioning of companies); (ii) the value network (the ways through which companies interact with their suppliers and reorganize their own internal activities. Geissdoerfer & al. (2018, p. 714) define Circular Business Models as "*Sustainable Business Models - which are business models that aim at solutions for sustainable development by creating additional monetary and non monetary value by the proactive management of a multiple stakeholders and incorporate a long term perspective - that are specially aiming at solutions for the circular Economy through a circular value chain and stakeholder incentive alignment*". Circular Business Models explore the transition from business model, to sustainable business model, and so one, to circular business model (figure 30).

Figure 30 : Comparison of traditional, sustainable and circular business models



Source : Geissdoerfer & al. (2018, p. 714)

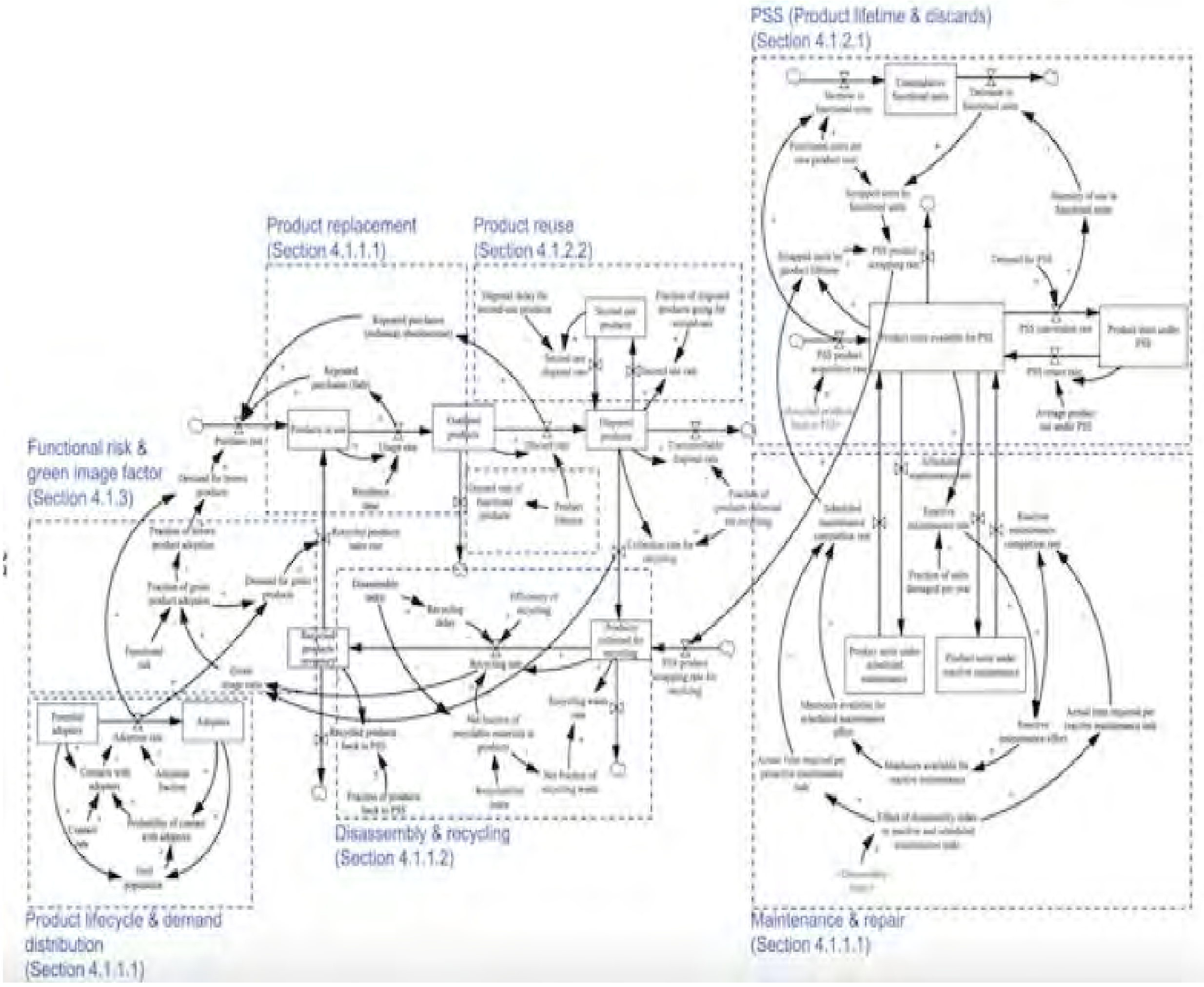
This framework has the advantage of offering several reading keys. Circular business models may address the issue of the resource cycle (Bocken & al.,2015). Resources are mainly intermediate inputs that affect production costs and prices, and generate negative externalities. It also involves understanding how flows (production) affect other flows within the industrial system (choice of materials) and outside it (the link between raw material requirements and extraction). The different Rs raise the question of how to loop the system. On the one hand, these loops can reinforce or, on the contrary, balance each other (the reuse loop can thus reinforce the recycling loop). On the other hand, nothing proves that a closed-loop system is more efficient than an open-loop system. Cooperation and co-products reinforce the idea that profit is created when several value chains interact. Circular business models may also challenge the length (narrow, large, direct, indirect) and the cascade effect of loops (tracking all the connections between products and co-products) for mapping the main drivers of the supply chain (product, technology, industry, strategy, sustainability..).

To conclude this section, it's worth remembering that for any project, it is interesting to adopt the LCSA method (Societal LLC) and to introduce it in the R-framework to map the Circular Economy strategies and to foresee how they influence the viability of value chains for the innovation cycle. So, it is possible to cross the economic analysis with the analysis at three spatial scales (micro, meso, and macro) to elicit generic interactions. Indeed, the next step could focus on economic indicators (such as variables providing relevant information for decision making, company-level reporting of SDGs), differentiating between end-product production (economic efficiency), consumption, waste management, and production of secondary raw materials (EC, 2015), and by adjusting them to the different properties of innovation process. A focus on creating value for the different actors in the value chain will be designed to ensure acceptance of the circular technologies by the full value chain. Economic indicators will be associated with environmental and social indicators to challenge the impacts of innovation on sustainability.

3. Iterative Nature of LCSA (Life Cycle Sustainability Assessment) and Systems Dynamics

Rather than a linearly proceeding process, LCSA integrates the results from environmental, social, and economic evaluations and maps the interactions between flows and stocks (Pinto, Sverdrup, Diemer, 2019). System dynamics may be useful to identify the loops and feed-back effects in the circular economy strategy of a company. In the Steel industry, lifecycle, replacement, reuse, recycling, repair.. are driving forces of the industrial system (figure 31).

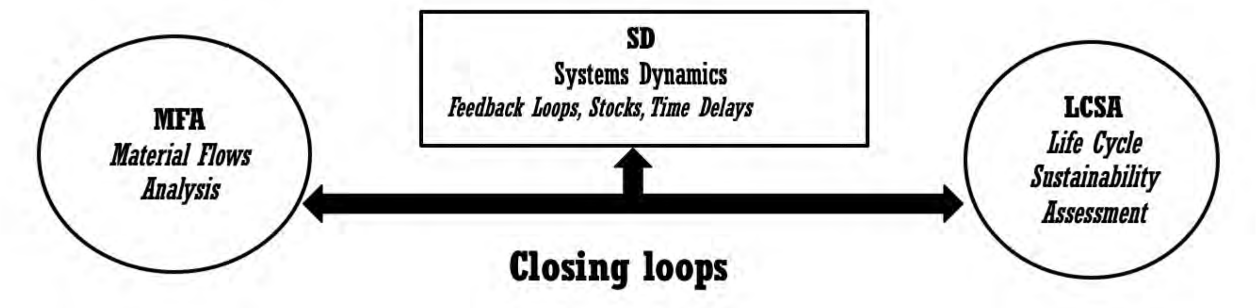
Figure 31 : Industrial dynamics and circular economy strategy



Source : Pinto, Sverdrup, Diemer (2019)

While Material Flows Analysis (MFA) is the starting point, systems dynamic (SD) is the method to model the flows (and the stocks) to reach the different targets of Life Cycle Sustainability Assessment (LCSA). There is a deep connection between SD and LCSA. Firstly, the definition of a system's boundaries, functional unit or scope of the system are quite similar. Secondly, inventory analysis and data collection (inputs and outputs such as raw materials, energy, co-products, waste…) provide practical guidance to perform sustainable goals (figure 32).

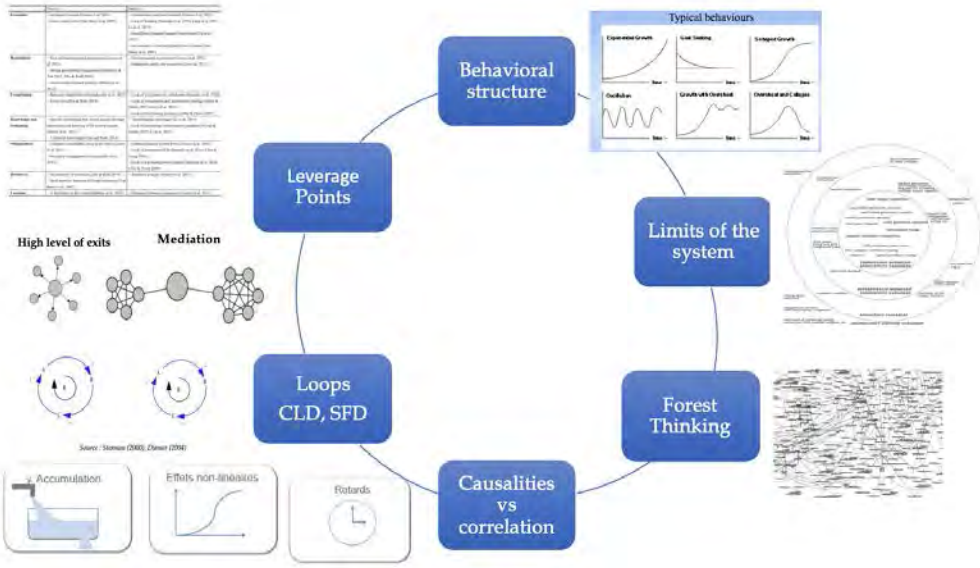
Figure 32 : MFA, SD and LCSA



Source : The author

Systems Dynamics is useful to identify behavioral patterns (figure 33), feedback loops, driving forces, time delays, archetypes, leverage points of intervention (Nedelciu, Diemer, 2020). All these different steps may improve the qualitative design of LCSA (Causal Loop Diagrams), the modeling part of the industrial process (stocks and Flows Diagrams), the data management (the choice of indicators) and simulations. Scenarios about sustainability are more consistent.

Figure 33 : Different steps in Systems Dynamics



Source : Diemer (2004)

Scenarios about sustainability become more consistent. Companies may improve efficiency, resilience and sustainability of the industrial process, including the involvement of stakeholders.

4. Industrial 'Toile' for LCSA (Symbiosis 4.0)

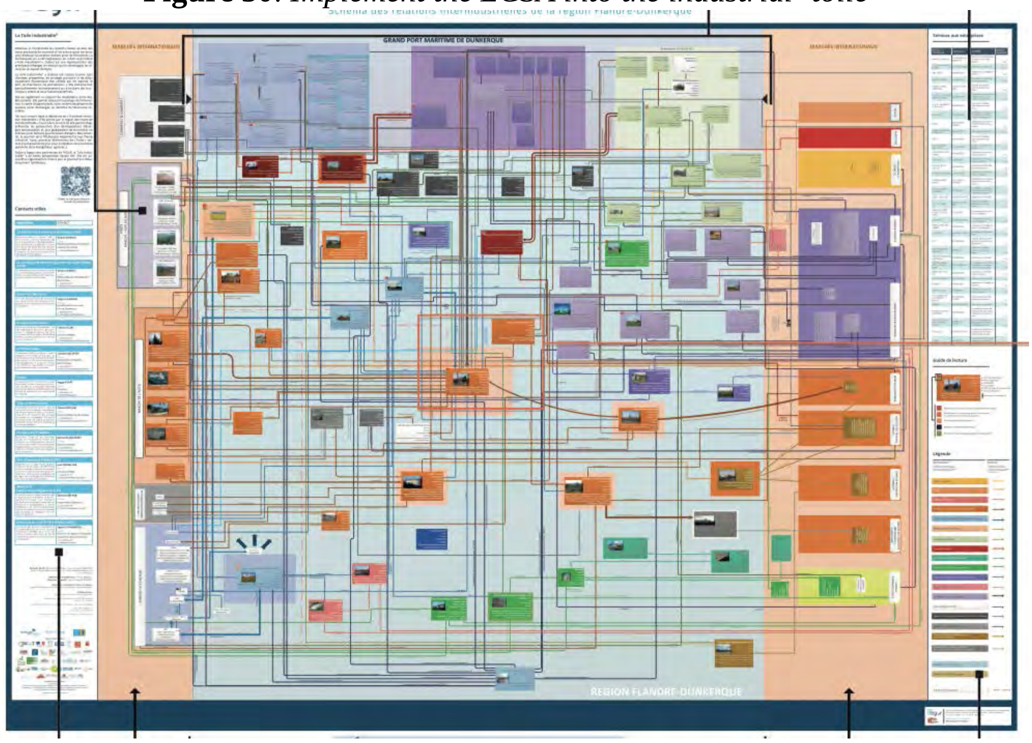
A life cycle perspective is as relevant for the social playground as it is for the environmental dimension and in a life cycle sustainability assessment (LCSA). To grasp all the dimensions of sustainability (environmental, social and economic), it is possible to map the flows, the stocks, the actors, and the cross-links between the actors. The industrial 'toile' (toile maker) developed by AGUR and Possibilizzeurs shows the viability and the complexity of the networks and relations operating at a territorial scale (figure 30).

Toile maker is based on the observation that digital technology opens up new opportunities for companies to create value. It gives them the means to optimize their activities, but also to reinvent themselves by positioning themselves differently in the value chain. More precisely, the data collected is seen as a raw material from which value can be extracted by analyzing it, correlating it with other sources (external and internal) or selling it where appropriate.

It is then possible to drive production optimization through data, by digitizing and interconnecting all links in the value chain, from customer order to delivery, including procurement and interactions with suppliers or subcontractors.

Symbiosis 4.0 refers to the digitalization of collaboration between companies in the same region. These synergies offer numerous opportunities for companies to achieve objectives of economic, environmental and social interest. Neighboring companies get to know each other and exchange views on their common needs and how they complement each other. Symbiosis 4.0 promotes the creation of a local industrial ecosystem. These synergies offer numerous advantages, such as cost reduction and the implementation of sustainable actions within companies.

Figure 30: *Implement the LCSA into the industrial 'toile'*



Source : The Author

The industrial 'toile' presents the flows and co-products exchanged by the various partners in the symbiosis, and can also be used to create product and company files, generate alert messages, cross-reference flows from different sources (water, energy, mobility, air quality, heat, etc.) and produce sustainability indicators.

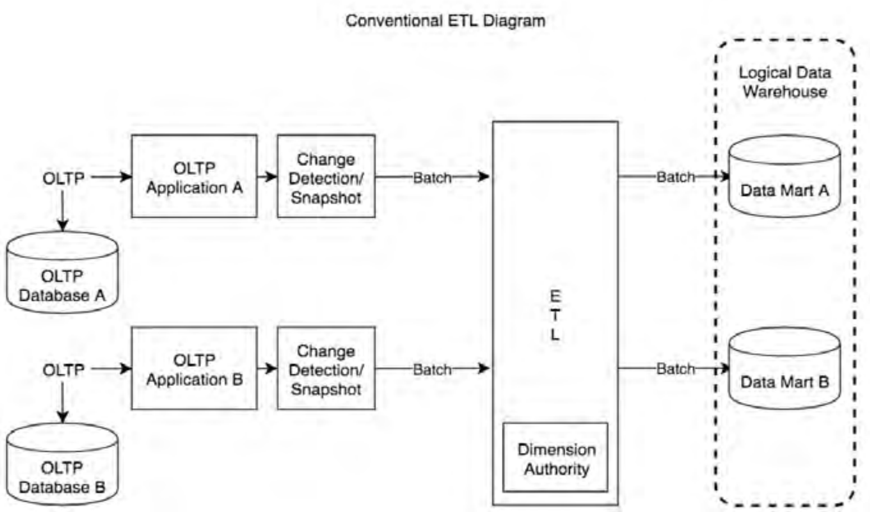
The 'toile' has attracted the interest of industrials for various reasons. They see it as a source of solutions allowing stakeholders in the economy to work together better. The tool may also serve to promote the local area by emphasizing synergies and economic use of resources. The tool helps local authorities to have a better understanding of the industrial network, with all its Strengths and Weaknesses, Opportunities and Threats (SWOT matrix). It is also a tool for visualizing future trends. If there is an unexpected event in the supply chain, the 'toile' will show the cascading effects on the value chain and the consequences for the partners.

Industrial 'toile' is an economic intelligence tool with multiple uses, including but not limited to: prospecting, circular economy, strategy, logistics, cooperation and synergy, and simulation. The 'toile' shows all the networks, flow, stocks, markets, and synergies between the businesses at a glance.

In practical terms, symbiosis 4.0 can be visualized using two excel files: (1) the file of entities (actor, company, infrastructures, etc.) with relevant characteristics in columns (name, benefit, products, GPS data, etc.), (2) the cross-flows file (environmental, social, economic) between these entities (impacts assessment table).These cross flows specify who generates the flow (e.g. waste) and who is likely to recover it.

The industrial toile has many objectives: model and visualize ecosystems and their upstream and downstream ramifications (entities / materials / infrastructure / intangibles (contracts, etc.); detect opportunities and weaknesses; massify data and simulate by changing indicators and visualize effects; centralize territorial data to enable "on-demand" modeling via a data manager; model influencing factors (tags = keywords); identify influencing factors that directly or indirectly affect the ecosystem and set up alerts; weather, 1st grade courses; set up an LCA system for entities (Life Cycle Assessment of entities); data temporality; dashboard integration for data massification; creation of a label for companies that share their data and contribute to the resilience of a territory; Tradeplace materials; systemic, georeferenced and sankey visualization; keep abreast of the latest news from local companies by setting up a keyword and thematic watch + identify company markets, use artificial intelligence to process and interpret data; simplify data retrieval and aggregation via ETL (Extract Transform Load) + define a territorial webmanager (figure 31).

Figure 31: *Extract Transform Lead*



Source : Kimball (2004)

In Symbiosis 4.0, data management serves stakeholders by transforming raw data into value. This value involves the exchange of corporate resource flows (energy, water, waste and by-products), the pooling of corporate services (collective waste management, rainwater collection and reuse, storage space, security, maintenance of green spaces, etc.), the sharing of equipment (boilers, steam production, effluent treatment units, etc.) or human resources (time-sharing jobs) between companies, the optimization of logistical flows between companies (pooling of material flows and transport capacities, etc.), the identification of new activities (development of new products or services based on a local resource or a common need, etc.) or the integration of the circular economy at regional and company level. Finally, Symbiosis 4.0 (the data management process) seems to open new opportunities to produce sustainable pathways and future scenarios.

5. Conclusion

The family of LCA (LCA, SLCA, LCSA) represents a valuable approach for accounting for sustainable impacts associated with production and consumption along a supply chain, as well as to support decision makers in different contexts. Indeed, these tools can be used to explore supply chains at different scales and industrial processes. Most of the time, the basic steps of Life Cycle Assessment (defining goal and scope of the assessment, inventory analysis, impact assessment, interpretation) are adapted to Social Life Cycle Assessment (SLCA). From the state of the art, the application of SLCA at the product level seems to be in the preliminary stage and relevant efforts are needed to improve the reliability, robustness, and applicability of SLCA approach. Every company has to consider that there are overlapping and complementary issues between LCA and SLCA. The integration and the complementarity of the two methodologies may trigger a few challenges: the variety of indicators, the assessment of positive and negative impacts, the interpretation of results, the involvement of stakeholders and the recognition of shared values, the decision making by different actors, among others. The next step is to drive the system to more sustainability (Life Cycle Sustainability Assessment, LCSA) and imagine the new business models (circular economy, from 4 Rs to 10 Rs). LCSA may become an important approach for the assessments of supply chains and offers a strong potential for improvements, but it requires a methodological effort (improving the interactive nature of LCSA with causal loop diagrams) and an analytical tool (industrial toile) to robustly support private and public policies.

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