H2020-MSCA-RISE-2018
ProCEedS Project

Promoting **C**ircular **E**conomy in th**e** Foo**d** **S**upply Chain

D1.2

Performance evaluation methodologies for agri-food supply chains

Social, environmental and economic assessment for policy–making support

This project has received funding from the European Union's Horizon 2020 Marie Skłodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

Acronym: ProCEedS

Title: Promoting Circular Economy in the Food Supply Chain

Coordinator: The University of Sheffield

Grant Number: 823967

Programme: H2020-MSCA-RISE-2018

Start: 1 September 2019

Duration: 45 months

Website: http://proceeds-rise.eu/

Consortium:

The University of Sheffield (USFD)

Universitá degli Studi di Napoli Parthenope (UPN)

South East European Research Centre (SEERC)

Uniwersytet Lodzki (Ulodz)

Instituto Nacional de Tecnologia Agropecuaria (INTA)

Solagri Societa' Cooperativa (SOLAGRI)

Nefeloudis Food Additives (TN)

Fundacja Rozwoju Przedsiebiorczosci (FRP)

Proteg Spa (PROTEG)

Agrilogistica Srl (AGRIT)

Regather Limited (RGT)

Udruzenje Proizvodjaca Grozdja I Vina Sa Oznakom Geografskog Porekla Srem - Fruska Gora (SREM)

Aquabiotech Limited (ABT)

This project has received funding from the European Union's Horizon 2020 Marie Skłodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

Deliverable Number: D1.2

Title: Performance evaluation methodologies for agri-food supply chains (social, environmental and economic for policy–making support)

Lead beneficiary: Universitá degli Studi di Napoli Parthenope (UPN)

Work package: WP1 – Performance Evaluation of Circular Food Supply Chains

Dissemination level: Public

Nature: Report (RE)

Due date: 30.06.2021

Submission date: 02.07.2021

Contributors: Renato Passaro, Andrea Genovese, Remo Santagata, Meletios Bimpizas-Pinis, Sergio Ulgiati, Serena Kaiser, Yanxin Liu, Yanfeng Lyu, Fabrizio Bellone, Olympia Charismiadou, Marianna Tsikriki.

This project has received funding from the European Union's Horizon 2020 Marie Skłodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

Contents

This project has received funding from the European Union's Horizon 2020 Marie Skłodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

List of Figures

This project has received funding from the European Union's Horizon 2020 Marie Skłodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

List of acronyms

CE – Circular Economy

(e-)LCA – (environmental) Life Cycle

Assessment s- LCA – social Life Cycle

Assessment LCC – Life Cycle Costing cLCC

– conventional Life Cycle Costing eLCC –

environmental Life Cycle Costing sLCC –

social Life Cycle Costing

EMA – EMergy Accounting

VSM –Value Stream Mapping

Sus-VSM - Sustainable Value Stream Mapping

This project has received funding from the European Union's Horizon 2020 Marie Skłodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

Executive Summary

Circular Economy is gathering more and more attention within many contexts, like the academic world, the business environment and the policy making sphere. Although this growing importance in so many fields, the implementation of concrete measures, whose impacts would be capable of changing both the production and consumption of goods and services, is still far from becoming a reality. This is also true for the production and consumption of food. Thus, it is fundamental to have scientific ways to analyse and understand the impacts of the food supply chain and consumption, so that the scientific world can be helpful in the decision–making processes of next future.

The methods which are here proposed as suitable tools for the analysis are Life Cycle Assessment (LCA), social Life Cycle Assessment (s-LCA), environmental Life Cycle Costing (eLCC), EMergy Accounting (EMA) and Sustainable Value Stream Mapping (Sus-VSM). They can provide an environmental and socio-economic perspective to the assessments to be developed. It should be noticed that these methods need to be improved when they are used to assess circular systems, having all of them (perhaps except EMA) being designed and used within linear frameworks. Improvements to these methods and their integration are part of this report.

In order to provide a more appropriate conceptual support to those who want to use this framework, the report not only aims at creating a view of circular patterns, but also of the specificity of each method and of the peculiarities to be detected in order to choose among the methods. Moreover, a future application of the framework in real case studies is foreseen, in order to create the opportunity to increase its diffusion and to refine its application in the various sectors of the agri-food system.

This project has received funding from the European Union's Horizon 2020 Marie Skłodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

1. Introduction

The kind of production which has been developing during the current age is without any doubt unsustainable, being based on the contradictory assumption that the exploitation of limited resources can be unlimited. Recent EU reports pointed out that about 50% of gas emissions contributing to global warming, about 90% of the disappeared biodiversity as well as most of negative consequences on water quality and availability may be due to the current intensive resource extraction and processing system (European Commission, 2020).

The same assumptions of unlimited resource availability and heavy consequences of intensive resource use on atmosphere, biodiversity and water are certainly applicable to the agri-food production.

The current awareness about the permanent negative impacts of linear production, in which "companies harvest and extract materials, use them to manufacture a product, and sell the product to a consumer— who then discards it when it no longer serves its purpose" (Ellen MacArthur Foundation, 2012, p.06) has generated a great interest on Circular Economy (CE), defined by the Ellen MacArthur Foundation as "an industrial system that is restorative or regenerative by intention and design" (Ellen MacArthur Foundation, 2012, p.07). This conception aims at retaining the value of produced goods and materials inside the economic system for the longest possible lifetime, generating the smallest possible amount of waste (European Commission, 2015).

Through several directives and initiatives, the European Institutions are adopting CE as the very basis of the industrial system in EU (European Commission, 2019). The main purpose of the ProCEedS project is to create the conditions for the knowledge about the transition towards CE models in agri-food industry, within the European framework. Several studies show that the transition to a circular model is still facing many difficulties not only due to the persistence of old linear designs and facilities, but also in view of the difficult comprehension of the positive effects that CE can have on environment, society and economy (Bocken et al., 2016; Lieder and Rashid, 2016). Therefore, at this phase it is important to shape the circumstances that could facilitate and subsequently disseminate the positive effects to the public, the industry, and policy bodies.

This project has received funding from the European Union's Horizon 2020 Marie Skłodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

In order to evaluate the impact of agri-food supply chain from several perspectives, different methods of sustainability assessment have been chosen and used. Among them, Life Cycle Assessment (LCA), Social Life Cycle Assessment (SLCA), Life Cycle Costing (LCC) and Value Stream Mapping (VSM).

1.1 The food supply chain

Food management is among the most complex production and consumption chains in worldwide economies. We most often disregard how many steps the food related processes must face, starting from the manufacturing of production tools (the industrial phase where, inter alia, equipment, fuels, fertilizers, are produced), the actual agricultural production and harvesting, the industrial or household manufacturing for food treatment, conservation, and cooking, and finally the organic waste generation and disposal. All these steps occur at different time and spatial scales, depending on the availability of environmental services (solar radiation, rain, topsoil, among others), energy, skilled labour, appropriate planning, and ability to monitor and assess the performance of each step and the quality and quantity of products.

Bio-based products are increasingly attracting the interest of researchers. Focusing on such a complex matter is not an easy task. Ulgiati and Zucaro (2019) pointed out the challenges linked to urban metabolism sustainability, identifying weaknesses and needs that are confirmed by Vassillo et al. (2019) in their survey about stakeholders' diversity, motivations, and engagement in Naples (Italy). A partial answer to the detected challenges can be found in several authors, who identify viable options and potentialities. Among these, Wang et al. (2020) developed a method for mapping renewable resources at regional level; Tagne et al. (2020) compare the African and Chinese progresses in the conversion of agricultural residues into biogas.

The complexity of phases, tools and products requires a number of assessment methods, each one designed for a specific task within the supply chain. This is true for business and market operators, policy makers, educators and trainers of workforce, at all levels, from local to national and beyond. Moreover, the different methods must be integrated to each other, to supply information that allow the entire system to develop and achieve the optimal result out of each phase, tool, and product. Therefore, the present project aims at developing a set of integrated assessment methods to be applied for the sustainable management of the entire food supply chain. In particular, the goal is to explore

This project has received funding from the European Union's Horizon 2020 Marie Skłodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

the conceptual basis underlying each approach, in order to ensure its appropriate application and potential improvement as far as new knowledge is available.

A number of case studies have been evaluated by far within the ProCEedS projects, some of which directly originated from secondments and others from the research performed within the Team, according to the list below.

Agricultural cases: The first two papers deal with local case studies of LCA applied to wine and olive oil production involving the circular reuse of residues. In both cases, LCA shows the advantages of converting residues into products to be used in farm or elsewhere. The third paper deals with Analytical Chemistry techniques coupled to LCA to explore the feasibility and viability of converting residues into activated carbon for pollutants uptake. Finally, the last manuscript couples LCA and EMA for expansion of environmental databases, with special focus on allocation techniques.

1. Ncube, G. Fiorentino, M. Colella, S. Ulgiati, 2021. Upgrading wineries to bio-refineries within a Circular Economy perspective: An Italian case study. Science of the Total Environment, 775: 145809.
2. Ncube, A., Fiorentino, G., Panfilo, C., De Falco, M., Ulgiati, S., 2021. Circular economy paths in the olive oil industry: A Life Cycle Assessment look into environmental performance and benefits. Submitted to Renewable and Sustainable Energy Reviews.
3. Tiegam, R.F.T., Tchuifon, D.R.T., Santagata, R., Nanssou, P.A.K., Anagho, S.G., Ionel, I., & Ulgiati, S., 2021. Production of activated carbon from cocoa pods: Investigating benefits and environmental impacts through analytical chemistry techniques and life cycle assessment. Journal of Cleaner Production, 288: 125464.
4. Ulgiati, S., Lyu, Y., Raugei, M., Zhang, X., Mellino, S., Ulgiati, S., 2021. The environmental cost and impacts of chemicals used in agriculture: An integration of Emergy and Life Cycle Assessment. Submitted to Renewable and Sustainable Energy Reviews.

Industrial food manufacture: The first manuscript, still in progress, deals with the performance of a Greek Company producing chemicals for flavouring and conservation of meat-based food. The research, performed by one secondee from Sheffield University and four secondees from Parthenope University, applies LCA, LCC and Social LCA to the company´s performance to explore its costs and benefits locally and over the larger country´s scale. The two Bachelor Theses (in Italian) deal with

This project has received funding from the European Union's Horizon 2020 Marie Skłodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

citrus production in Campania Region, with special focus on by-products and co-products in a Circular Economy framework. LCA is applied.

5. Manuscript in progress, Secondment TN, Greece: Bimpizas, M., Kaiser, S., Santagata, R., Liu, Y., Lyu, Y., Passaro, R., "Environmental and social assessment of food additives production in a Circular Economy perspective: A case study in Thessaloniki".
6. Bachelor thesis of Flavia Borzelli, Bachelor Degree in Biology, Parthenope University of Napoli. Sostenibilità ambientale di un 'impresa agricola in un percorso di economia circolare. Il caso studio della produzione del limone di Sorrento IGP. April 2021.
7. Bachelor thesis of Marco Portarapillo, Bachelor Degree in Biology, Parthenope University of Napoli. Analisi del Ciclo di Vita della filiera produttiva del limone, dell´olio di oliva e dei loro co–prodotti aromatici ed alimentari, con esempi innovativi di economia circolare. June 2021.

Household use: Modelling techniques and the Stella Software are applied, coupled to elements of LCA impacts, to develop an environmental policy tool using the Metropolitan City of Naples as a case study.

8. Casazza, M., Xue, J., Du, S., Liu, G. and Ulgiati, S., 2021. Simulations of scenarios for urban household water and energy consumption. PloS one, 16(4), p.e0249781.

Waste management and recovery: A very complete review of proposed food waste recovery pathways worldwide is proposed. LCA and EMA are then used in parallel to explore benefits and costs.

9. Santagata, R., Ripa, M., Genovese, A. and Ulgiati, S., 2020. Food waste recovery pathways: challenges and opportunities for an emerging bio-based circular economy. A systematic review and an assessment. Journal of Cleaner Production 28: 125490.

Wastewater management: Scenarios are explored and compared for recovery of useful biomass (algae, chemicals, bioenergy) from urban and industrial wastewater, in a Circular Economy perspective.

10. Catone, C.M., Ripa, M., Geremia, E. and Ulgiati, S., 2021. Bio-products from algae-based biorefinery on wastewater: A review. Journal of Environmental Management, 293: 112792.

This project has received funding from the European Union's Horizon 2020 Marie Skłodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

11. Zaharudin, Z.A., Brint, A., Genovese, A. and Piccolo, C., 2021. A spatial interaction model for the representation of user access to household waste recycling centres. Resources, Conservation and Recycling, 168: 105438.
12. Colella, M., Ripa, M., Cocozza, A., Panfilo, C., Ulgiati, S., 2021. Challenges and opportunities from circular wastewater management. The case of Campania Region, Italy. Submitted to Journal of Environmental Management

The present report will be articulated in the following sections. Section 2 provides a general methodological overview. Section 3 provides insights about the potential interactions among assessment methods and opportunities coming from their integration. In Section 4, some applications resulting from the integration of the proposed methods will be presented. Drawn conclusions along with future research perspectives will be provided in Section 5.

2. Sustainability Assessment methods for Agri-Food Supply Chains

As already said before, this chapter deals with the some of the main methods which are currently used to perform the sustainability assessment of production systems. Even if this study is focused on agri-food supply chain, it is important to notice that the described methods are valid for every other kind of production. The methods which will be introduced are Life Cycle Assessment, Social Life Cycle Assessment, Life Cycle Costing, EMergy Accounting and Value Stream Mapping.
These methods have been applied within the ProCEedS project on several case studies in the agri-food system. Some of these case studies originated within the secondments performed by the project partners and some developed by the research activities of the latter, for a better understanding of the potential problems linked to the different steps of the food supply chain. In some cases, these research activities have been reported in published or submitted papers, as listed and discussed in Section 4.

2.1. Life Cycle Assessment

This method gives importance to the assumption that, to perform a reliable assessment of the environmental impact of a product or service, it is necessary to consider its whole life cycle, "from cradle to grave", passing through all the stages of production, distribution, use, disposal. To give an

This project has received funding from the European Union's Horizon 2020 Marie Skłodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

example of what "from cradle to grave" means, it can be considered that the life cycle of a product or service starts with the resource extraction and ends with final disposal (Ulgiati et al., 2018). Life Cycle Assessment gives the possibility to list and evaluate all the inputs and outputs which are relevant from an environmental point of view and, consequently, to assess their impacts on the environment, during the whole life cycle of a product, a material, or a service.

Interesting examples of LCA procedures developed within our research team are related to (i) food production, to (ii) waste management and (iii) waste to energy & materials conversion. In particular:

(i) Pollaro et al. (2020) investigated the sustainability of Sheep and Goat rearing in the Campania Region (Italy), focusing on the circularity potential within the farm as well as within an expanded regional area. Ncube et al. (2021) addressed the advantages of Circular Economy patterns in wine production coupled to recovery of wine pomace. In so doing a diffuse biorefinery perspective was designed.

(ii) Municipal solid waste treatment at urban level was studied by Ripa et al. (2017), focusing on the diversity of waste and management options, while Buonocore et al. (2018) discussed a series of LCA indicators to assess the environmental efficiency of urban wastewater treatment.

(iii) Ripa et al. (2017) investigated the viability of the available options for municipal solid waste conversion to biofuels, while Florio et al. (2019) applied LCA to bio-methane production from organic waste through different upgrading technologies. Papermaking from chemical pulp and bio-based chemicals were investigated respectively by Corcelli et al. (2018) and Fiorentino et al. (2019), trying to compare LCA indicators and economic indicators with the aim to point out the feasibility of each process. Finally, Tagne et al. (2021) used the LCA approach to show the viability of activated carbon production from cocoa pods. In so doing, the large production of waste coupled to cocoa production can be decreased.

As clearly shown in the above examples, performing an LCA can have many reasons, among which the main ones are:

- To detect the most relevant contributors to environmental impacts (hotspots) and to design opportunities of improvement;

This project has received funding from the European Union's Horizon 2020 Marie Skłodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

- To examine how much each stage of the life cycle contributes to the total environmental damage, in order to improve products and processes and prevent the burdens to be transferred from a phase to another;
- To make comparisons among products for internal and external communication, thus creating the basis for product certification or for labelling, as in the case of environmental product declarations;
- To work for a wider participation of stakeholders in environmental policy-making process developed by both institutions and the business world;

The four main phases of an LCA are (EC, 2021):

a) The definition of the goal and scope of the study;
b) The Life Cycle Inventory, which is the phase where all resource inflows and process emissions are quantified and listed, in order to provide a reliable basis for impact assessment;
c) The Life Cycle Impact Assessment, in which the potential impacts of resource depletion and polluting emissions are investigated and quantified and then assigned to different impact categories, in order to understand the potential interaction of the process with selected phenomena in the biosphere and its global sustainability;
d) Finally, the interpretation of the results and the suggestion of actions aimed at mitigating impacts and improving the production process.

a) Goal and scope definition

In the first phase, an explanation is provided about why the study is performed. The reasons are: the specific product, the purpose for which the results will be used, the functional unit (which is the product and/or the function for which the transformation process is performed), the needed data and the specific kind of sensitivity analysis. This step also creates a description of the investigated system in terms of function and boundaries (ISO, 2006a). Some very important elements of the study are described in this phase, namely:

- The use of LCA tool is motivated and the answers to be found through its use are detected;
- The product is precisely defined, as well as its life cycle and its function;
- The functional unit is defined;
- The boundaries of the system are described;

This project has received funding from the European Union's Horizon 2020 Marie Skłodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

- The description of data and of all the assumptions and constraints about them is given;
- There is the presentation of all the criteria about LCIA procedure and of the interpretation That will follow;
- The communication procedure and the target audience are identified;
- When it is the case, the modality of peer review are described;
- The kind and format of the report, which will be drafted for the study, are outlined.

The goal and scope are two fundamental elements for the solidity of LCA. They can be accommodated during the LCA study by adapting them to needs that were not identified when the study was started.

Functional unit

Defining the functional unit is fundamental for an LCA study. When considering a system, the functional unit is a measure of the functions performed by the system itself and represents a term of comparison for each input and output, so that it becomes possible to compare different systems capable to provide the same function/service. The precision in the definition of the functional unit can really affect the whole study because it is used as a reference.

The Definition of the System Boundary

To have a precise identification of the life cycle phases and processes to be investigated, it is fundamental to define the system boundary, which includes all the processes of interest in our system and ensures that all the possible impacts are considered enough (Thomas, 2011). It is important to define and separate input and output flows, when designing a system boundary. Figure 2.1 shows the most common classifications, which are used to outline the system boundary.

This project has received funding from the European Union's Horizon 2020 Marie Skłodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

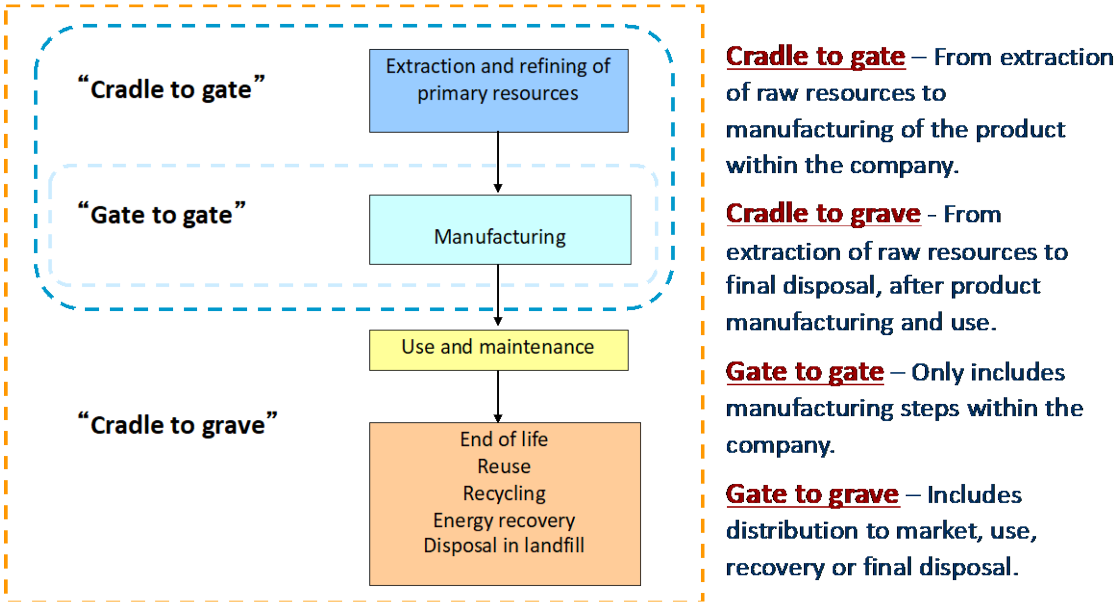


Figure 2.1 - Most common options used in LCA to define system boundaries.

b) Inventory analysis

This can be a very long and difficult phase of an LCA. In order to collect data, there might be the need of surveys, interviews, accessing reports and documents, etc. The purpose of this data collection is to create a list of all the inputs in terms of material and energy and of all the outputs, such as emissions and waste. This is needed for each process and activity in the studied system. There are specific software to process and model all the collected data: some of them are SimaPro, GaBi and OpenLCA.

Allocation among product systems

Considering the process which is being analysed, allocation is the partition of the material and energy inflows and outflows among all the products generated by the investigated process (ISO, 2006a). There is a specific procedure for allocation, established by the International Organization for Standardization (ISO). In ISO 14044 (ISO, 2006a), this procedure is defined in this way:

- First of all, avoiding allocation is the preferable choice, which can be performed by splitting the investigated process into two or more sub-processes;

This project has received funding from the European Union's Horizon 2020 Marie Skłodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

- If this is not possible, inputs and outputs should be distributed among the different products or functions of the system following a criterion that reflects the fraction of each co-product on the total production, expressed in economical or physical terms;
- If there is no clearly identified physical relation for a sound allocation procedure, then inflows and outflows can be assigned to the products and functions based on other relations among them. Data related to inputs and outputs might be allocated among co-products according to thermodynamic properties (exergy) or their market value (ISO, 2006b). The latter should be discouraged whenever possible, due to its variability depending on criteria that are variable from country to country;

c) Life Cycle Impact Assessment

In this phase each inflow or outflow of energy and matter translates into a quantified potential environmental impact (Ulgiati et al., 2018). Impacts can be due to some specific resource depletion (excess use of water, fossil fuels, topsoil) or midpoint of endpoint effect due to emissions of chemicals or heat. The purpose is to clearly identify the misuse of resources and the damage on the environment. For this reason, in the impact assessment phase the inventory data are interpreted and converted into quantified impact indicators. The latter serve as a key to understand the consequences of the process dynamics and suggest improvement policies. Brentrup et al. (2004) define the list of impact category indicators as environmental profile. There is the possibility to relate the indicator values to reference values, making a normalisation that allows getting a better interpretation of the environmental profile. This offers the opportunity to have a clear understanding of the magnitude of each indicator resulting from the product system i.e., the object of our study (ISO, 2006b).

d) Interpretation of results

In this phase there is a discussion about the results and a comparison to appropriate benchmarks. This is also the phase in which conclusions and recommendations are presented, together with the identification of the limitations of the study.

The ideal attitude of LCA is to model every single impact of a product over its entire life cycle. Of course, this is impossible in practical terms, so there is the need to introduce simplifications to the system boundaries. Among the most used simplifications, the "cut off" consists in excluding data that are considered too small or negligible or outside the window of interest of the analysis. But this can

This project has received funding from the European Union's Horizon 2020 Marie Skłodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

lead to some bias, owing to the fact that "cut off" is often subjective, so perhaps an Input-Output LCA (IOA) approach might be a very useful way to overcome this subjectivity. The system boundaries of IOA includes the entire economy. The IOA framework is based on monetary flows associated to resources exchanges and can be easily converted into physical quantities and environmental externalities (Martinez et al, 2019).

LCA has been applied in different areas and industries. It has been adopted in the macro-scale and in micro-scale areas, in the public sector and in individual organizations. As regards the sectoral application, it has been mainly adopted in industrial and manufacturing production, while fewer applications are in eco-design and product engineering. In the area of industrial production and infrastructure, the LCA approach is widely applied to different sectors such as: biofuels, energy, waste and water treatment, agriculture, mining, automobiles, plastics, construction, oil and gas extraction, transport, communications (Jacquemin, 2012). In the last decade, many applications have been addressed in the food production industry. They mainly focus on product assessment rather than process or sector evaluation (e.g.: milk, peach, apple production) (Valsasina, 2017; Vinyes, 2017) and are mainly addressed on the boundaries of cradle-to-grave and cradle-to-factory assessment, spanning multiple stages of the product life cycle (Ahmad et al., 2019). Furthermore, a recent analysis on published articles concerning the application of LCA to food supply chains has highlighted that these applications pay little attention to social and economic problems and to potential circular economy choices (Vidergar et al. 2021).

In recent years, the research Team has carried out various LCA applications in the agri-food supply chains favouring a combined sector/product approach (olive oil, cocoa pods, food additives, lemons) (see section 1.1.).

2.2. Social Life Cycle Assessment

The Social Life Cycle Assessment aims at assessing the social impacts deriving from a product or a service over its life cycle. It is still an incomplete and under development method. According to Andrews (2009), s-LCA aims at evaluating the social and socio-economic aspects of products and identifying their positive and negative impacts over all the phases that generate a product or a service, "from cradle to grave". One of the interesting aspects of Social LCA is that impacts are investigated in terms of positive (opportunities) and negative (risks) impacts. Indeed, s-LCA considers social

This project has received funding from the European Union's Horizon 2020 Marie Skłodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

impacts as positive or negative effects of process´ pressures on social endpoints (i.e., the well-being of stakeholders) (STAR-ProBio, 2019).

S-LCA is performed according to the same procedure and steps used for an LCA, within the ISO 14044 framework (ISO, 2006a; ISO, 2006b), as mentioned in section 2.1 above.

One of the problems that s-LCA faces is the possibility that results are biased due to the fact that social indicators may be linked to specific interpretations and subjective perspectives. This subjectivity may affect the results, considering the subjectivity of the weighting factors used to determine the relative importance of each impact category (STAR-ProBio, 2019). In the presence of subjective factors, a reliable comparison of social indicators between studies can be very limited and ineffective. Despite this uncertainty, only in 2013 did UNEP and SETAC elaborate specific guidelines to get to define a standardized knowledge and a uniform evaluation method (UNEP and SETAC, 2013). S-LCA focuses on social aspects such as hierarchies in workplaces, management and planning of production processes, unemployment, skills and know–how, needs for infrastructures in society, education and culture, illegal child labour, poverty, and fair trade. A social assessment requires a clear identification and involvement of stakeholders (e.g. workers, consumers, local associations, business operators, unions, and all other players in the area). An inventory of categories and subcategories is crucial: it allows to address social, sociologic, and socio-economic impacts of process products over their life cycle. At the same time, knowledge of sociology, anthropology, and management sciences is needed for a successful evaluation (UNEP and SETAC, 2013; van Haaster et al., 2017; Zamagni et al., 2015). The multi-disciplinarity that this method represents is undoubtedly interesting, even if its incompleteness and its aspects still under development leave room for many doubts and questions to which research will have to provide answers in the future.

2.3. Life Cycle Costing Method

The conventional version of LCC represents the assessment of all costs associated with the life cycle of a product/service that are directly covered by the main producer or user in the product life cycle (from conception to production and to the end of its useful economic life). The assessment basically focuses on real, internal costs (White and Ostwald, 1976) and is applied in various industries including the agro-food industry (Korpi and Ala-Risku, 2008; Frankl and Rubik, 2000; Stillitano et al. 2021; Notarnicola et al. 2015; Fiedler et al. 2008). In detail, LCC applied in the agribusiness industry allows

This project has received funding from the European Union's Horizon 2020 Marie Skłodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

to perceive and capture the impacts that arise during the product life cycle (Savic et al. 2019) while it is considered a relevant method to be developed and disseminated to face food waste by adequately addressing the recommendations to stakeholders for the prevention, enhancement and management of the phenomenon (De Menna et al. 2016)

Looking at the landscape of valuation methods from a historical perspective, conventional LCC is an established one considering that it was introduced by the US General Accounting Office in the 1930s to include operating and maintenance costs in public procurement. After the World War II, cLCC was formally adopted and developed by government bodies and agencies. Indeed, according to some scholars (Epstein, 1966; Gluch and Baumann, 2004) the history of LCC began in the US Department of Defence in the mid-1960s which adopted cLCA in the 1960s for the acquisition of high-cost weapon systems, (Hoogmartens et al., 2014; Hunkeler et al. 2008). Later, in the 70s mandatory LCC was included in US public purchase of and buildings, (Hunkeler et al. 2008). In Europe, in the same period, several countries started to use LCA method in order to support the decisions of both company management and government bodies (Hunkeler et al. 2008; UNEP, 2013; Sala et al. 2016). Only a few studies and analyses have addressed the application of LCC in agribusiness in the 1980s and 1990s. Indeed, the number of these studies has increased over the past two decades (Pellettier 2014; Savic et al. 2019; Iotti and Bonazzi 2014; Fiedler et al. 2008) and also involved the urban agriculture niche (Peña and Rovira-Val, 2020). As for the food waste and food system, studies have addressed LCC application only at the beginning of the third millennium (Notarnicola et al. 2015; DeMenna et al. 2016).

Since 1980, the life cycle costing has undergone an evolutionary process that has blossomed in the development and conceptualisation of multiple approaches and applications. Part of these approaches was aimed to comprehend of how useful and appropriate the LCC approach is for sustainability decision-making (Gluch and Baumann, 2004; Alejandrino et al. 2021). In general, only two of the approaches that emerged, have been broadly recognized in the scientific literature: environmental LCC (eLCC) and social LLC (sLCC). The former translates external environmental costs (externalities) into internal ones. The latter includes all external costs rooted in a societal level and consider welfare losses and gains related to the re-allocation of resources (Skovgaard et al. 2007, Møller et al. 2014). Both these approaches reflect the social and environmental emergence that have featured the socio-economic and policy context in the last decades at worldwide level. eLCC and s-LCC, by embodying

This project has received funding from the European Union's Horizon 2020 Marie Skłodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

in the assessment process a larger range of costs, are built-on and expand the scope and boundaries of conventional LCC, as highlighted by Hunkeler et al. (2008).

The adoption of these two methodologies in the context of agri-food system is still limited. A confirm emerge from a very recent research addressing the state of the art of life cycle applications in the Circular economy perspective in the period 2014-2021 (Stillitano et al., 2021). The research, based on a systematic literature review analysis, highlights that while LCC approach combined with other methods has been adopted in 9.5% of the entire set of 84 case study analysed in the agri-food system, no case study deals with the s-LCC.

As for eLCC, this approach considers all costs associated with the life cycle of a product, incurred by one or more actors over the product's lifetime, including externalities, which are foreseen to be internalized in the decision-relevant future (Hunkeler et al., 2008; Swarr et al., 2011). eLCC goes beyond conventional LCC as it assesses the impact of external end-of-life and monetary external costs (waste prevention or disposal) (Bierer et al., 2015; Norris, 2001). It is also useful to point out that eLCC is consistent with the multi-stakeholder perspective of physical product life cycles as opposed to conventional LCC that has a single-stakeholder perspective (Heijungs et al., 2013). Furthermore, eLCC also differs from cLCC in that the former approach also considers the 'physical' life cycle of a product instead of the marketing life cycle commonly considered in cLCC.

The perspective on which the eLCC has been built since its inception is to provide a comprehensive combination of both the environmental and economic performance of a product or service, in order to support technological and managerial decision-making. For example, support companies' investment strategy decisions by comparing the eLCC of alternative products having different energy consumption performance across their lifecycle (Iraldo et al., 2017).

The perspective of the social LCC, from a broad point of view, is to identify and assess social repercussions and implications generate from the activities and process to produce goods and services. In particular, sLCC is aimed to support companies to conduct business in a socially responsible way by providing information about the potential (positive and negative) social impacts on people caused by the activities in the life cycle of their product (Dreyer et al., 2006).

In particular, sLCC embody all costs associated with the life cycle of a product/service that affect people whether today or in the future (Hunkeler et al., 2008) such as taxes associated with market transactions (Ciroth et al., 2011). Comparing sLCC and eLCC we can claim that the former already

This project has received funding from the European Union's Horizon 2020 Marie Skłodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

includes the monetization of externalities, while the latter broadens the scope to incorporate non-monetary externalities (e.g., emissions reduction associated with eco-packaging, or loss of biodiversity).

Given the feature of eLCC to provide a comprehensive combination of both the environmental and economic performance, this method is adopted in this document to be part of the framework under construction. For this reason in the following the eLCC is more deeply discussed by adopting the framework proposed by the code of practice of the SETAC-Europe Working Group on Life-Cycle Costing (Hunkeler et al. 2008). The SETAC code of practice proposes four steps, which are commonly implemented while performing an eLCC study: (i) Goal and scope definition; (ii) Information collection; (iii) Interpretation and identification of hotspots and, (iv) Sensitivity analysis and discussion.

i) The first step to take is the definition of scope, goal, and system boundaries of the eLCC study to be realised. This must be defined before the study starts and in accordance with the organization functional unit. Furthermore, in order to properly define the main cost that stakeholders have to bear, it is essential to outline the perspective of the analysis (producer, consumer) to be adopted. Costs are divided in internal costs and external costs. The former are defined as the costs along the product/service life cycle or which are incurred by a stakeholder (supplier, distributor, EoL manager). These costs are related to different phases of the product/service lifecycle and can be associated to an organization business cost. They can refer to environmental and social externalities which affect stakeholders' wellness (carbon footprint, effects of air pollution on human health). The external costs (externalities) specify the impacts measured in monetary terms which are not directly faced by any actor within the life cycle. Nevertheless, given these costs can be relevant for decision-making, they should be properly considered in the eLCC study.

ii) The second step deals with data and information requirements for eLCC which depend on the scope and goal of the study. To collect cost information to realize an eLCC study requires an intensive data gathering process. When data and information are not available in company databases other techniques have to be adopted such as estimation methods which represent the most common technique adopted in the life cycle costing field. Cost estimation techniques can be classified into three categories: *Parametric* (based on the application of equations describing relations between cost and the attributes of a product, service or process); *By analogy* (used to perform cost estimations of new

This project has received funding from the European Union's Horizon 2020 Marie Skłodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

products and services based on the identification of cost characteristic of similar existing products); *By engineering* (adopts data on working times and production inputs to estimate the direct costs of a product; indirect costs are considered by means of allocation rate techniques) (Asiedu and Gu, 1998; Korpi and Ala-Risku, 2008).

iii) The third step is the identification of environmental hotspots and related trade-offs between environmental pressures and environmental benefits. A hotspot is the most important source of environmental impact that can be analysed using established methods for the investment analysis based on cash flow analysis (such as net present value, internal rate of return), break-even point analysis, pay-back period analysis.

iv) The fourth step is addressed to perform a sensitivity analysis having the purpose of identifying how target variables are affected based on changes in input variables ("what if" or simulation analysis). Although a sensitivity analysis is bounded by the fact that only one input can be changed at a time for each round, it is possible to overcome this limit by adopting simulation methods able to estimate the relationship among the parameters adopted. The sensitivity analysis allows to acquire further elements of knowledge on the behaviour of the observed variables (particularly of the key variables) in order to bring out and discuss the results obtained (for example, the parameters used, the assumptions made, the elements of potential uncertainty, the variability of the results are evaluated).

Based on the four steps described, all the elements of economic and environmental knowledge are now available to discuss the strengths and weaknesses of the results obtained (e.g.: sector/context scenario, technology, costs, life cycle information, environmental hotspots, environmental pressures and benefits, sensitivity of the variables adopted). This knowledge base and the related summary assessments, which represent the key results of the LCC, is then utilised to make recommendations and guidelines aimed at supporting the decision-making process. (Hunkeler et al., 2008).

Although the use of the LCC method and its derivations has grown in recent years with applications in many sectors and fields of activity, some critical elements remain for their more robust and broad application. These critical elements are the focus of a debate among scholars and experts which, in turn, underlines the attention to the developments and the potential of the LCC in connection with the growing environmental problems and sustainability emergence. The major critical points that are reported can be addressed to *methodological aspects* (lack of calculation methodologies, the deficiency of

This project has received funding from the European Union's Horizon 2020 Marie Skłodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

a standardised procedure, lack of robustness for valuation methods for externalities); *technical aspects* (data availability, use of different currencies, quantification of the monetary value of selected costs, definition and choice of discount rates, lack of dedicated software package); *policy aspects* (relevance of LCC for different stakeholders, weak consistency among environmental, economic and social of different approaches); *motivational aspects* (long term benefits and future issues are beyond the scope of original decision-makers) (IISD 2009; Costa et al., 2019; Swarr et al., 2011; Alejandrino et al. 2021). Among the few applications of LCC to nondurable food products a critical point emerged is the variability of methodologies within the studies when LCC is used within environmental management. Furthermore, LCC is mainly used to assess investments in food production plants (Settanni et al., 2010). In this view, the authors have reviewed the methods for combining LCA of food products with macroeconomic analysis and two main implications have emerged. The first is the need to extend the system boundaries up to include all the complex transactions that characterize a national economic system at its entity. The second is the possibility to assess economic effects of specific actions (e.g.: the effects of the diet) taken to improve the ecological performance of food production systems. The study recalls the need to expand research towards the applications of LCC to food products, given the growing interest in this method and in order to help build an appropriate approach to take into due consideration the agri-food system specific factors. (Settanni et al., 2010)

2.4. EMergy Accounting

The ecologist Howard Odum has developed a new approach to environmental and resource accounting named “EMergy Accounting”, spelled with an “M”, (hereafter EMA) (Odum, 1994, 1996; Brown and Ulgiati, 2004). The approach looks at resources from the point of view of their generation, i.e. the point of view of biosphere and the time and space scales involved. In so doing, a supply–side instead of a user–side approach is adopted, a kind of environmental cost of production. EMergy is defined as the available energy (exergy) directly and indirectly used to generate a resource by the biosphere as well as to generate a product or a service within the economy. Therefore, every resource is assessed starting from the driving forces (solar radiation, geothermal heat, gravitational potential) that generate the environmental services (e.g., wind, rain) which in turn support photosynthesis, soil formation, water cycling, fossil fuels and minerals cycling and storage, biodiversity, and life. (Brown

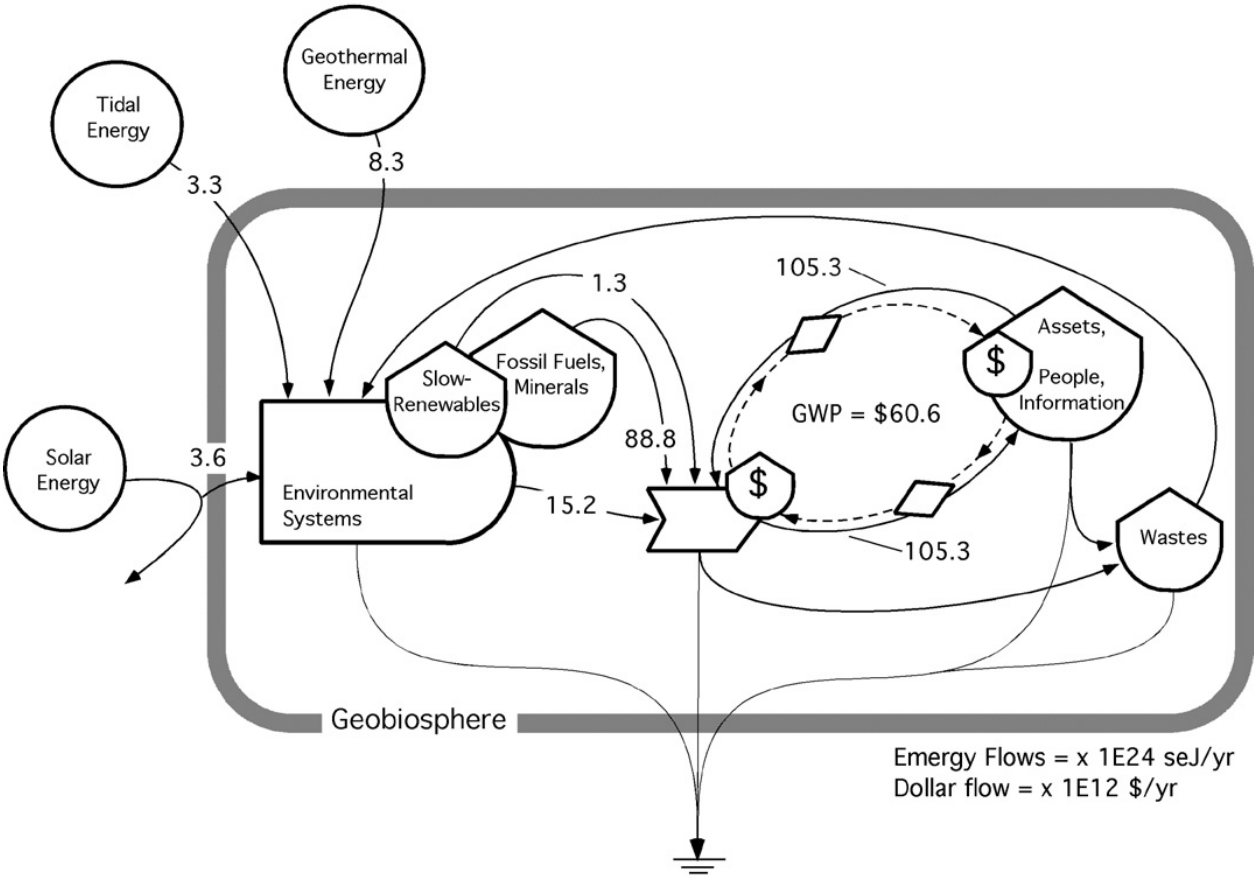
This project has received funding from the European Union’s Horizon 2020 Marie Skłodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

and Ulgiati, 2010; Brown et al., 2011; Brown and Ulgiati, 2011; Brown and Ulgiati, 2016a; Brown and Ulgiati, 2016b).

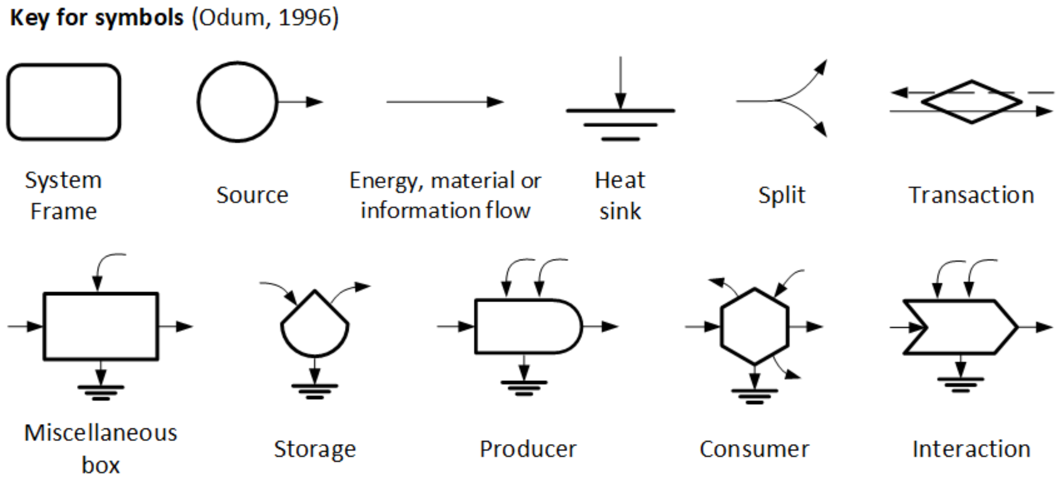
Calculating the work of biosphere and the work of humans to generate any kind of resource or product is a way to assign to this product a value, namely an environmental production cost within the evolutionary "trial and error" processes of Nature. These processes take place over time within the environmental domains (e.g., earth crust, atmosphere and oceans), of which also humans are part with their social and economic activities (Odum, 1996) (Figures 2.2a and 2.2b and Figure 4.2). This value goes much beyond the neoclassical conception of value, which is based on willingness-to-pay concepts. Furthermore, the EMA value expands its view much broader than the LCA resource depletion categories, in that EMA also looks at much larger time and spatial scales for resource generation instead of simply "checking" inside the existing resource storages to assess how much is left and the emissions released by the local process. For the sake of clarity, the main characteristics of the EMA approach is to look at resource generation by biosphere processes. The generation time and procedure, not the amount presently available, is considered crucial by the emergy approach. No doubt that photosynthesis driven by solar energy, i.e., the process that generates food, but also materials (think of wood) and fuels (think of the million years of fossil fuels generation from photosynthetic substrates), can be considered among the most interesting processes for the emergy approach, which starts from solar energy and proceeds towards the concentration of solar energy into biological materials. Of course, EMA also considers other kinds of concentrations (e.g., minerals cycled by deep heat), since also these processes contribute to food production via the generation of topsoil over millennia of degradation of minerals to provide nutrients to plants metabolism. In a like manner, water evapotranspiration, driven by solar energy, is one of the main contributors to temperature regulation and to plant growth in photosynthetic processes. Water value in conventional economics depends on the processes to extract water from underground storages and spread it through pumping systems. Instead, in the EMA method, water value depends on the evapotranspiration process, which is not valued in the market, despite its huge value to regulate the temperature of the planet. EMA does not look at direct impact categories (e.g., global warming potential, acidification potential, toxicity) that are instead the realm of LCA. As an example, fossil fuels are not evaluated starting from underground extraction (as in LCA) but starting from phytoplankton generation through photosynthesis and sequestration over millions of years (Brown and Ulgiati, 2011; Brown et al., 2011). Solar energy is used as a common denominator to express all flows in a standard unit, the solar emjoule (sej). In a way,

This project has received funding from the European Union's Horizon 2020 Marie Skłodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

EMA is a different measure of cost, beyond monetary cost (when tomatoes cost very little, this means that workers to pick tomatoes have been paid very little). EMA clarifies the biosphere work needed to generate and replace the resources (nutrients, fertilizers, water, energy) used in food production.



(a)



(b)

This project has received funding from the European Union's Horizon 2020 Marie Skłodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

Figure 2.2 – (a) Systems diagram of material and energy pathways of the biosphere driven by solar radiation, gravitational energy of tides and geologic/geothermal processes (data refer to the year 2008; Brown and Ulgiati, 2011). (b) Main symbols used in systems diagram modelling (after Odum, 1996).

Examples of EMA studies with special focus on the food supply chain are the following:

a) **Energy and materials.** Santagata et al. (2017) assess the recovery of slaughterhouse residues to produce electricity. Their results compare different procedures for the calculation of emergy indicators and identify some cases in which the calculated UEV competes with the UEV of fossil fuels. Corcelli et al. (2018) calculate emergy–based sustainability indicators for papermaking, comparing the use of different source trees.

b) **Water and food trade.** Rotolo et al. (2018) apply the emergy method to the international trade of argentine maize, putting into evidence the trade advantage for the purchaser of primary commodities, leaving the exporting country in an emergy loss condition. Liu et al. (2019) apply the Emergy approach to water extraction and distribution to urban consumers in Beijing.

The total emergy, as well as a large number of other emergy–based indicators can be used to assess the environmental performance of an economic process (Brown and Ulgiati, 2004). In particular, the emergy investment per unit of product (UEV, Unit Emergy Value) assumes the role of a characterization (or equivalence) factors to convert the numerical measurement of stocks and flows (different units) into emergy units (sej) characterized by the same (solar based) quality, thus overcoming the limitations of other approaches. For the sake of clarity, in terms of environmental cost, 1 kg of iron is not the same thing than 1 kg of copper; 1 kg of corn is not the same thing than 1 kg of apples; 1 MJ of hydroelectricity is not the same thing than 1 MJ of fossil powered electricity. In fact, it takes different work of the Biosphere (energy, time, space, other resources generated previously) to generate different products. EMA uses these equivalence "production" factors (UEVs) to convert each inputs values (in the inventory of a process) to a standard unit (grams to solar emjoules; joules to solar emjoules; $$ to solar emjoules; hours to solar emjoules, etc) and be able to sum up the different production costs, much beyond the instability of market prices.

Being EMA a relatively recent approach, based on the uncertainty of biosphere processes, the basis to which all calculations are referred to has been subject to several updates. Odum (1996) considered as

This project has received funding from the European Union's Horizon 2020 Marie Skłodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

reference baseline the total annual emergy driving all biosphere processes and calculated a total emergy U (solar radiation, geothermal heat, gravitational potential) equal to 9.44E+24 sej/yr. Further updates led to the present Geobiosphere Emergy Baseline of 12.00E+24 sej/yr (Brown et al., 2016c). UEVs and indicators calculated with reference to previous baselines must be proportionally updated or recalculated.

EMA starts its procedure by defining its window of interest, i.e., the system boundaries of the process and by drawing a diagram to include the most important components, flows and processes inside the boundary and between inside components and outside sources. This diagram allows a deeper understanding of driving forces, interactions, processes, waste generation, outside recipients (e.g., market or other systems) and show them to the audience for appropriate discussion (Odum, 1996). The total eMergy (U) requires that all inflows are first converted to the same unit (emjoules) and then summed up (Brown and Ulgiati, 2004; Brown and Ulgiati, 2010; Brown et al., 2011; Brown and Ulgiati, 2011; Brown and Ulgiati, 2016a; Brown and Ulgiati, 2016b).

Unlike other methods, EMA also quantifies and includes into the assessment the resources supporting information and know-how, infrastructures, large scale services, such as health and transportation structures and services. This is performed through a Labour and Services accounting. Services are indirect labour. L/S in turn require support (education, mobility, housing, health care; in other words, infrastructure, and information). The emergy investment for labour and Services accounts for the emergy supporting infrastructures and information which contribute to the investigated process (Ulgiati and Brown, 2014). L&S can be quantified through hours of Labour and/or money paid for direct and indirect labour, multiplied by the emergy/money ratio or the emergy per hour of the country where the process occurs. Other accounting methods most often do not include L&S quantification, which makes difficult to compare the results under study with results outside local boundaries (Santagata et al., 2019).

2.4.1 EMA applied to Industrial Processes

EMA operates at the interface between human and natural systems (Ridolfi et al., 2018), and for this reason becomes a useful tool to evaluate the efficiency of resource use (Ghisellini et al., 2014). Recent applications have also been developed in the agri-food industry (Ghisellini et al., 2014; Ridolfi et al.,

This project has received funding from the European Union's Horizon 2020 Marie Skłodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

2018). It also supports policy decisions by means of a set of multidimensional and multi scale indicators that focus on environmental loading and environmental and economic losses of natural capital and ecological functions (Santagata et al., 2020b). Indeed, EMA provides a supply side perspective (nature) to a process evaluation, while other methods only look at the consumer side (industry) (Raugei et al., 2014). This integration among different perspectives is very valuable and should not be disregarded.

2.5. Value Stream Mapping

Value Stream Mapping (VSM) is a method rooted in the lean production paradigm for redesigning productive systems. Also known as material and information flow identification, VSM aims to map processes and to identify their main criticalities (Braglia et al. 2011; Hines and Rich, 1997). In particular, it is adopted to lean practitioners to identify and reducing wasted time and inventory, reduce process cycle times, implement process efficiency by improving material flows. VSM is mainly used at firm or organization level (micro-level) (Singh and Sharma, 2009) even though applications at supply chain (meso-level) have been proposed (Suarez-Barraza et al., 2011).

More recently, VSM has been expanded to include broader environmental analysis and indicators to develop interactions between lean and green manufacturing approaches. In this view, VSM applications have been proposed for estimating value adding energy and non-value-added energy consumption (Verma and Sharma, 2016) or to reduce water use while improving operational performance (EPA, 2011). Some features of the VMS (such as the reduction of waste generation, of overproduction, of stock excess, etc.) are consistent with sustainability and circular economy principles. This posits the VSM at crossroad between economic sustainability and economic efficiency and goes back to the stream of research and thought on economic development aspiring to sustain the so-called orientation towards eco-efficiency by identifying "a way of putting together the different purposes of the modern economic world, characterized by numerous fluctuations and a spectacular evolution in order to be sustainable and efficient" (Borza, 2014, pp. 1355).

From the viewpoint of application techniques, VSM basically uses flowcharts that document each step of the process. The VSM techniques were developed in the 1990s in the frame of the lean manufacturing paradigm. Then, they were conveyed in visual tools that highlight all critical steps in a specific production process and quantifies the input in terms of time and volume absorbed in each

This project has received funding from the European Union's Horizon 2020 Marie Skłodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

production stage. Thus, the stream maps show the flow of both materials and information as they progress through the process, and provide evidence of points and places where the process can be improved by visualizing both its value-adding and wasteful steps. In the 1990s, various leading lean production scholars have contributed to the practical adoption of VSM by defining conceptual and analytical elements (such as hierarchy of waste removal operations, value-stream mapping tools, classification of different types of waste) (Monden,1994; Hines and Rich, 1997; Jones, 1995). Other authors also proposed formal procedure for the operational implementation of VSM (Serrano Lasa et al. 2008; Braglia et al. 2011). Specifically, Woehrle and Abou-Shady (2010) have proposed a lean procedure based on four steps. Conversely, no official standards have been developed for reports to be published, although many corporate reports already adopt comparable reporting formats.

As said previously, in the last decade VSM has increasingly focused on environmental analysis and indicators. In fact, according to Sparks (2014) VSM shows a weakness of metrics to assess performance in terms of environmental and societal sustainability. In this view, Sustainable Value Stream Mapping embodies a suite of environmental and social parameters and indicators concerning resource consumption, energy, and labour conditions. The first attempt to bring sustainability issues back into VSM was proposed by Simons and Mason (2002). They created a first extension of the method to track the CO2 and GHG emissions of a production process and improve its sustainability. In reality, this application did not contemplate social parameters since the authors believed that they would automatically improve with the improvement of environmental and economic parameters.

Other applications were then proposed with a view to sustainability but without being effectively addressed to consider all the sustainability pillars from the perspective of the Triple Bottom Line (TBL). The first TBL oriented applications of the VSM appeared in 2014 when a group of scholars of the University of Kentucky (Faulkner and Badurdeen, 2014; Brown et al., 2014) developed the Sustainable Value Stream Mapping (Sus-VSM) in order to capture economic, environmental, and societal sustainability of firms. Moreover, specific metrics (environmental and social) and visual symbols were proposed to implement the method. Environmental metrics considered were classified in: a) water consumption, b) raw material usage, and c) energy consumption. Social metrics were classified in: a) Physical work and, b) Work environment. An integration between Sus-VSM and LCA also has been proposed by scholars and will be discussed in the following (Djatna and Prasetyo, 2019).

This project has received funding from the European Union's Horizon 2020 Marie Skłodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

An extension of the VSM oriented to sustainability was adopted in the chilled food industry to reduce waste, which occurs as over-production and inefficient resource usage (Norton and Fearne, 2009). In detail, this VSM application evidenced the importance of relationships and information flows between retailers and manufacturers in the food industry. In fact, the inefficiencies of the relationship and communication system, such as volatility of orders and inaccuracy of forecasts, result in incorrect estimates of material requirements and production plans. This diminishes the efficiency of the processes and implies the generation of overproduction to ensure the availability of the product on the market. Both results increase the waste generation. This application, according to the authors, intended to propose a tool that could be easily and autonomously used by small companies. The environmental indicators that were embodied in the method were defined by the DEFRA (UK Department for Environment, Food and Rural Affairs) and were grouped in: a) basic indicators (solid waste, liquid waste, CO_2 emissions); and b) industry specific indicators.

A further interesting evidence of VSM application in the food industry is based on a review of relevant literature that is aimed to contribute both to reduce food waste and to establish links with nutrient retention in food supply chains (De Steur et al. 2016). The study considers VSM applications in different world countries and different type of foods. VSM permits the emerging of various production problems impacting on food waste in four hotspots (primary production, processing, storage, and foodservice/consumption). Two types of food losses/wastes emerge: discard waste (more diffused) and nutrient losses (less diffused). These losses are then attributed to various supply chain hotspots (defects in products both in food processing and storage, unnecessary inventory, over-production, inappropriate processing). Among others, two main results of this study that are related to the VSM method should be highlighted. First, this study highlights the importance of sharing information between the players in the supply chain in applying VSM to reduce the food waste according to a multi-stakeholder approach. Secondly, the application of VSM can be extended to the adoption of different lean production principles (e.g., just-in-time) that could favour the continuous improvement of the agri-food supply chains thus significantly impacting on the food losses/wastes reduction. Although its efficiency and diffusion, some criticisms against VSM can be addressed. Firstly, the lack of a monetary representation of the indicators that emerge from the adoption of the method represent a limit to being able to consider the Sus-VSM as a framework that solidly responds to all the pillars of the sustainability manufacturing (economic, social, environmental). This therefore binds the

This project has received funding from the European Union's Horizon 2020 Marie Skłodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

contribution that the method can provide in contributing to any analysis of the production process aimed at improving its sustainability performance. Another criticism that can be raised is that Sus-VSM, although it is a process-oriented method, does not consider those processes and activities which are oriented to extend the life cycle of products such as repair or remanufacturing and which therefore play a key role in the perspective of the circular economy. The main concerns of the method are limited to eliminating or reducing waste and identifying solutions for the reuse of resources. From this point of view, in the perspective of the transition to the circular economy, the method shows a portion of incompleteness.

3. Integration among methods: conceptual aspects

The limitation to evaluate the performance of a process by only using one method (be it LCA, EMA, or others) has become clear in the recent years. Each method is characterized by specific time and spatial scales, specific design that makes it able to address only a part of the performance (economic, environmental, waste production, job creation, efficiency, among others). Consequently, not only a sufficient number of methods must be used, but also it is important to know how their results can be integrated, what is the sequence of their application, what is their specific boundary, what is the uncertainty of their results).

3.1. Integrations: strengths and limitations

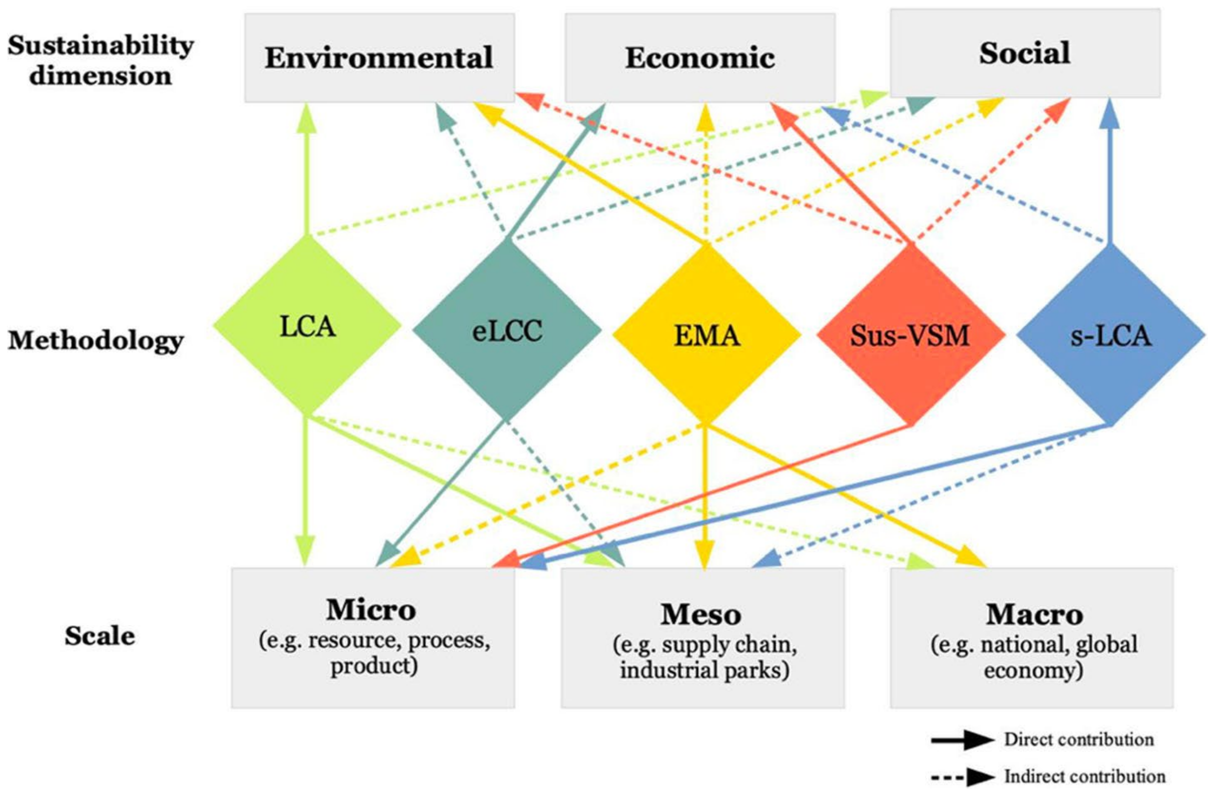
Figure 3.1 shows the potential integration of the methods analysed in this report, the sustainability dimensions that they are able to consider and finally the space and time scales where they occur (micro, meso and macro) (Oliveira et al., 2021). As shown, the methods focus on different scales, interacting to each other with support and feedbacks. What is important is that dimensions, methods and scales interact, horizontally and vertically, in that they affect, support and clarify each other top–down and bottom–up, for a clearer and comprehensive picture and decision–making process. Concerning their sustainability dimensions, the following considerations apply:

- LCA and EMA mainly focus on environmental aspects. Of course, this does not mean that they disregard social and economic aspects (e.g., effects of pollutants on human health and the role of Labor and Services on the stability of an economic process);

This project has received funding from the European Union's Horizon 2020 Marie Skłodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

- eLCC and Sus-VSM are mainly concerned on the economic aspects; however, they also consider wasted resources and social dimensions. For example, eLCC quantifies the externalities of environmental impacts, while Sus-VSM includes in its framework human labour conditions and excess material and energy uses;
- s-LCA is designed to address social aspects, but does not disregard related economic considerations, such as fair salary, human rights and employment.

According to the most recent literature, LCA was separately integrated with LCC, s-LCA, EMA and VSM (Oliveira et al., 2021), we have not found any published paper in which Sus-VSM, LCC and EMA methods have been integrated with each other. This is still an important weakness of the integration process and requires more efforts for a roadmap towards a tool that supports environmental, economic, and social policy–making in an integrated and comprehensive framework. The benefits of integration are very clear also from the point of view of the analyst, because all of these methods may rely on the same inventory of input and output flows, similar diagramming approach and comparable boundaries.



This project has received funding from the European Union's Horizon 2020 Marie Skłodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

Figure 3.1. Potential Integration among assessment methods, scales of interest and sustainability dimensions (Oliveira et al., 2021).

3.2. Integration case studies

A first conceptual idea concerning the integration of economic dimensions of sustainability into Life Cycle Assessment was developed in the year 1987 (Finkbeiner et al., 2010). Later, Norris (2001) suggested steps to integrate cLCC and LCA. An integration of social aspects within Life Cycle Assessment was proposed, more or less in the same period, by O'Brien et al. (1996), who designed a Social and Environmental Life Cycle Assessment (SELCA) tool.

Most recently, a debate about how and to what extent economic and social aspects should and could be integrated into Life Cycle Assessment concepts and tools (Costa et al., 2019). The problem was that applying LCA, eLCC and s- LCA separately forces them to "work" in isolation and being unable to display their potentialities (Sala et al., 2013), within the same system boundaries but without including mutual relations in the analysis. An important result of such debate was the development of the Life Cycle Sustainability Assessment (LCSA) by Kloepffer (2008), demanding a simultaneous LCA, eLCC and s-LCA application. The LCSA framework allows the joint evaluation and comparison of the results achieved by the three assessment approaches. Yet, the LCSA framework still suffers from several challenges, namely a lack of harmonisation among methods, the lack of appropriate databases capable to put economic and social pillars within a life cycle perspective and serious problems for the design of impact assessment methods. Finally, it should not be disregarded that sensitivity and uncertainty analysis methods still need to be developed (Costa et al., 2019).

Recently, s-LCA practitioners kept improving and developing this approach and related indicators (Costa et al., 2019; Petti et al., 2018), while at the same time new potential integration patterns with LCA and LCC were proposed. Heijungs et al. (2013) developed a computational tool able to calculate LCA and LCC indicators at the same time, overcoming the lack of transparency of life cycle costs calculation procedure, through aggregated eco-efficiency indicators carrying out economic and environmental information. An additional link between eLCC and LCA was developed by Bierer et al. (2015) by means of an extended Material Flow Cost Analysis (MFCA, i.e. a useful approach towards harmonisation of the two methods, in particular monetary and non-monetary figures. However, in

This project has received funding from the European Union's Horizon 2020 Marie Skłodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

spite of the efforts to integrate these approaches, a number of crucial problems still need to be considered and solved, among which:

- Functional unit – It is very hard to define a functional unit that applied to all of these methods to be integrated in order to make clear reference of quantitative and qualitative data to a same FU (Petti et al., 2018);
- System boundaries –How to successfully identify appropriate and consistent boundaries for LCA, eLCC and s–LCA (Benoît et al., 2010; Petti et al., 2018);
- Metric system – The monetary units used by eLCC do not easily match with physical flows and different units that characterize LCA evaluations (Hoogmartens et al., 2014). Further, the qualitative and quantitative data characterizing s-LCA assessments cannot be translated into the purely quantitative data used by eLCC and LCA (Petti et al., 2018);
- Data requirements – In LCA, the effort to collect data about input flows in order to calculate environmental impacts of production processes of a particular product is not easy and cannot be avoided. Otherwise, in eLCC assessments inflows are measured by price, much easier and more homogeneous procedure (e.g. price of raw material derives from labour costs of extraction and processing) (Hunkeler et al., 2008).
- Normalisation and weighting methods – Transparency of the procedure decreases when normalization and weighting procedures are introduced, due to assumptions and average values, so that uncertainty and subjectivity become a major problem.

3.2.1 LCA and Sus-VSM integration

A small number of trials have been made in order to find a suitable integration of LCA and Sus-VSM towards a unified tool (Paju et al., 2010; Thiede et al., 2016). The scientific literature only shows two papers that conceptually and experimentally address the need to integrate Sus-VSM with LCA (Djatna and Prasetyo, 2019; Vinodh et al., 2016). The first one used the results of a Sus-VSM as input to a gate-to-gate LCA. Then, results of the gate-to-gate LCA were expanded into broader scope LCA (e.g. cradle-to-cradle or cradle-to-gate). These LCA results can also be used as a feedback into a Sus-VSM, in order to identify the best approach for an improvement of the investigated process within an environmental perspective (Djatna and Prasetyo, 2019). Vinodh et al. (2016) tested a similar approach

This project has received funding from the European Union's Horizon 2020 Marie Skłodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

but limited their scope on comparing the current state Sus-VSM with the future state of Sus-VSM to make decisions about strategies for waste disposal. However, the very small number of published papers makes integration of LCA and Sus–VSM still in its first steps and do not provide significant perspectives and advice about directions to be selected.

3.2.2 Integration of LCA and EMA methods

LCA and EMA are characterized by great similarity in the way they are performed, and they provide different and complementary perspectives answering to different questions (Santagata et al., 2019). In recent years, several attempts have been made to merge the LCA consumer side perspective and EMA donor side perspective. Marvuglia et al. (2018) tried to develop a software application based on LCA databases and compatible with EMA algebra rules, Ingwersen (2010) proposed to include EMA as an upstream LCA impact category. Ghisellini et al. (2014) used LCA and EMA to evaluate the use of photovoltaic electricity and the use of manure for fertilization and biogas production within different livestock scenarios in Italy and Poland, certifying the reduction of environmental impacts and improved efficiency and better environmental performances.

Still, most of the related research delivered more of a joint use of the two methods, than a proper integration of perspectives and insights.

Santagata et al. (2020a) proposed an integrated procedure, called LEAF (LCA & EMA Applied Framework) for the simultaneous use of the two methods in a holistic perspective capable of providing additional information for enhancing the sustainability of the investigated systems.

LEAF develops and compares several scenarios studied by means of LCA and EMA. It is structured, as shown in Figure 3.2, in three main steps:

- Ex-Ante LCA: the system is analysed by means of LCA to understand the main hotspot contributing to environmental impacts;
- EMA scenarios developed around the considered hotspots. Different solutions and perspectives can be applied, the system may be studied as it is from a Business-as-usual perspective, material and technological efficiency improvements can be introduced, as well as the substitution of materials and energies with renewable ones. Methodological scenarios might be developed too;
- Ex-Post LCA performed for each scenario, to identify the variations in terms of environmental burdens.

This project has received funding from the European Union's Horizon 2020 Marie Skłodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

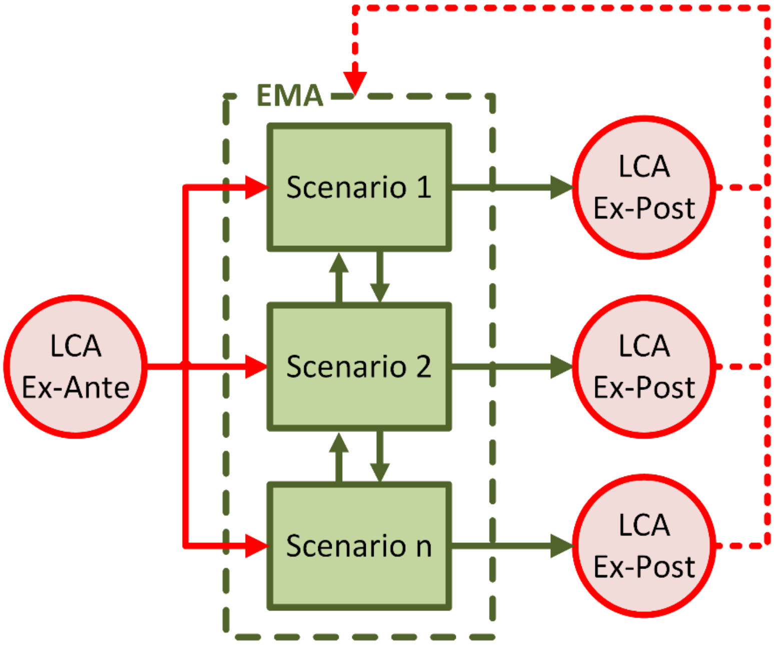


Figure 3.2 - LEAF (LCA & EMA Applied Framework) – An integrated tool for environmental policy making (after Santagata et al., 2020a).

The sequential application of LCA and EMA performed within LEAF is able to deliver a multi perspective, holistic analysis with indicators from both donor and consumer side points of view. The generated indicators can be used within decision making, discussions between stakeholders and in general in sustainability related practices. Results about paper production from waste paper and textiles (Santagata et al., 2020a) as well as about dairy production (Oliveira et al., 2021) clearly show the advantage of methodological integration. An emergy-LCA analysis of municipal solid waste management was performed by Liu et al. (2020) trying to express both upstream and downstream aspects of waste management.

4. The need for indicators to assess Circular Economy practices

The Circular Economy system is a concept designed to be regenerative and self-sustaining, based on three main pillars:

1. Preventive design, to lower the use of resources and reduce waste by increasing efficiency;

This project has received funding from the European Union's Horizon 2020 Marie Skłodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

2. Increase the share of renewable resources used;
3. Re-use and recycle of by-products and waste.

A useful consideration to put CE in practice has to be done by means of participatory strategies and "circular" governance, according to the evaluation performed by Ghisellini et al. (2019) concerning waste management in Italy. In fact, environmental, economic and social issues cannot be addressed just as top-down regulations that rely on new technologies. There is a strong need for production and consumption models, that call for a large sharing of values and a related participatory governance model. (Ghisellini and Ulgiati, 2020)

However, addressing and measuring CE may be difficult, and there is still no consensus on a suitable method for assessing CE systems or on how and what is needed to be measured to assess CE strategies (Niero and Kalbar, 2019). Most of the published papers about CE indicators however disregard the micro level, mainly focusing on the macro and meso levels. Scenarios of urban household water and energy consumption as well as municipal waste circular management were simulated respectively by Casazza et al. (2019) and Casazza et al. (2021).

Suitable CE indicators are needed for careful monitoring and proper assessing of human systems and economies (Geng et al., 2016). According to Linder et al. (2017), CE assessments at product level should avoid environmental feasibility analyses and should instead pay more attention on circularity measures, while Pauliuk (2018) proposed a new set of indicators designed for quantitative assessment of product systems, specially focusing on circularity, environmental and economic aspects. It is clear how innovative indicators are required to evaluate the environmental performance for closed-loop CE-oriented systems and quantify benefits, constraints and costs, while keeping track of feedbacks and interconnection between CE oriented systems (Brown and Ulgiati, 2011; Geng et al., 2013; Giannetti et al., 2015). According to Geissdoerfer et al. (2017) conventional mono-dimensional tools are not able to fully capture CE features and the strong link existing between CE and sustainable development, which suggests as crucial to use indicators capable of capture at the same time the different aspects involved.

The search for suitable indicators in recent years gained much interest. Niero and Kalbar (2019) proposed the use of Multi Criteria Decision Analysis to couple CE indicators with LCA. Santagata et al. (2020b) proposed EMA as a suitable and comprehensive source of indicators thanks to its peculiar

This project has received funding from the European Union's Horizon 2020 Marie Skłodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

algebra rules and it is considered as able to capture and enhance the complex CE framework. EMA accounts for the support coming from renewable and non-renewable, local and non-local resources, information, know-how and labour and services, from a donor-side perspective, thus expressing value as what is invested to deliver products and/or services. EMA indicators can also express and highlight the proper use of natural capital and investigate ecosystem functions (Santagata et al., 2019).

4.1 Case by case methods selection and integration

To overcome the difficulty in measuring a proper CE transition and accounting for economic, social, and environmental features within the micro and meso level, a framework has been developed to facilitate method selection and the integration among different accounting methods. Adopting the language of the systemic diagrams formulated by Odum (1996) (Figure 2.2b), the proposed framework is represented in Figure 4.1 using as a model the functioning of a local economy.

The local economy is receiving natural support from the ecosystem in the form of different renewable driving sources, as sunlight, deep heat, energy in rain, in winds, and in the tidal cycle. These sources maintain the generation of raw materials (wood biomass, minerals, metals, etc.) happening in the various biosphere compartments (earth crust, forests, oceans, etc.). The raw material are then extracted and processed before directing them to industrial transformation and distribution, within and outside the considered boundaries, to consumers. Waste, by-products, end-of-life materials and used goods from every component are collected to be fed back through reuse, repair or recycle, or to be routed to final disposal (e.g., landfilling, incineration, etc.). Additional support to the network comes from virtual storages of external goods and assets (machinery, fuels, energy, etc.), i.e., by the energy stored for durable uses over the timespan of the investigated process, in so regulating and equalizing the flow. In a CE perspective, also the recovered goods would be part of the storage of assets. The various emissions and discharges from every joint of the network are returned to the biosphere across the local economy boundaries. Further, still looking at the diagram in Figure 4.1, the support coming from direct and indirect labour is highlighted, as well as the economic support to the entire system in the form of a virtual storage of money maintained by a currency inflow (economic transaction in exchange for assets produced by the considered local economy). Lastly, every thermodynamic loss of energy at every component of the system is connected to a heat sink, representing the losses of available energy according to the second Law of thermodynamics.

This project has received funding from the European Union's Horizon 2020 Marie Skłodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

Such a complex system needs to be investigated by means of several different methods, in order to capture all of its environmental, economic and social features. The achieved results should be integrated whenever possible. As mentioned in Chapter 3, LCA results and procedures have been integrated with results from other methods, so far, while instead other methods were not integrated to each other so far. LCA measures environmental impacts and resource use of human dominated processes from a downstream perspective; eLCC considers economic transactions, revenues and costs, over the entire life cycle of products/services; S-LCA focuses on the social and sociological consequences of processes and products, namely their positive and negative impacts over a product´s life cycle; EMA expands the analysis also accounting for natural input flows and for labour and services, from an upstream perspective and giving information about the renewable/non-renewable and local/non-local aspects; Sus-VSM mainly identify input and output flows within transformation processes, providing suitable inventories for the other methods. Conventional Economic Assessment (CEA), shown in Figure 4.1, and its indicators (e.g., GDP, revenues, profits) are clearly not enough to describe the complexity of the represented system.

The mentioned methods could be further integrated and complemented among them and with each other. Results could be assessed and interpreted in a comprehensive way, and information from a method may become an input for another method.

This project has received funding from the European Union's Horizon 2020 Marie Skłodowska-Curie European Research and Innovation programme under grant agreement ProCEedS No 823967.

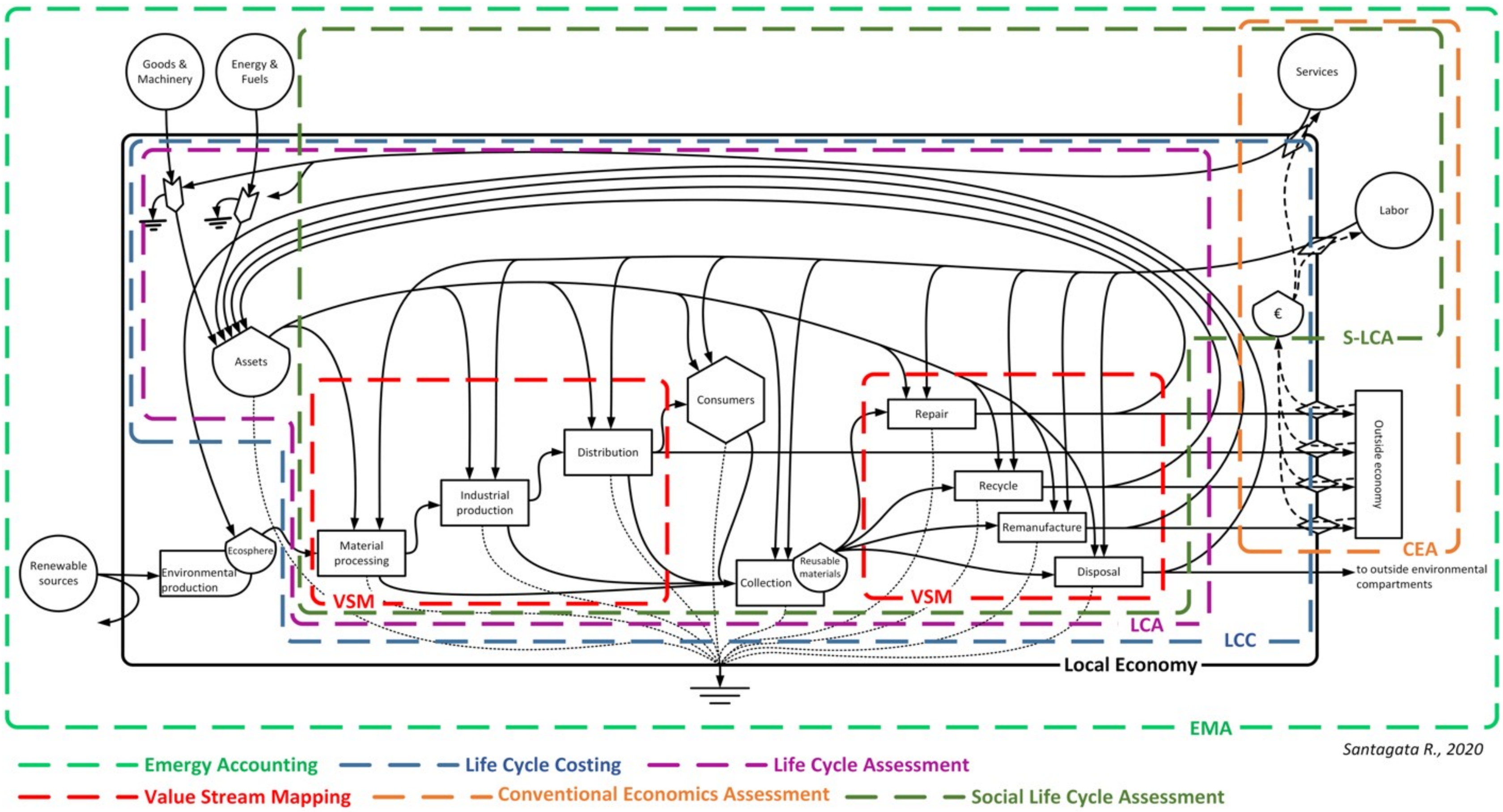


Figure 4.1 - Representation of a circular economy system at regional or country level, with comparison among boundaries of each method.

4.2 Perspectives and Limitations

Different methods provide different perspectives, and the simultaneous application of methods can provide at the same time different and complementary sustainability related answers. The proposed framework tries to identify and address divergences among the methods, in order to be able to choose the best way for their simultaneous application and integration. In particular, when focus is placed on the economic, social, technological and health complexity that characterize the food supply and management chain, the above-described method may not be sufficient to address and solve the challenges and suggest solutions, although within a CE perspective. The mentioned methods have been created and are still connected to a linear "take-make-dispose" economic paradigm. Future research about CE should focus on the development of proper, feasible indicator for circularity enhanced systems.

5. Conclusions

More key points of discussion emerge from the overview analysis carried out in this report regarding the methodologies for assessing the sustainability of production systems and their orientation to support the transition to circular economy. However, two elements seem to predominantly emerge. On the one hand, it comes out that each of the methodologies considered (LCA, s-LCA, LCC, EMA and VSM) plays a specific role and represents a different point of view in evaluating the sustainable evolution of a production process. A confirmation of this consideration is that each method addresses specific sustainability indicators. On the other side, the methods under analysis have been generated to be used in a perspective of sustainability of linear production systems. It follows that they show a low propensity to be adopted in the evaluation of circular production systems as well as they show weaknesses in describing and analysing the related feedback loops.

Two main paths could be followed to overcome these weaknesses and limitations. The first path consists in providing useful and adequate indications (through a practical guide or the formulation of guidelines) to identify the most appropriate method to be used according to the specificities of the different production scenarios. The second is to deepen the methodologies with the aim of supporting a further integration of these methods to obtain results that are more complete. This integration could be addressed to provide a homogeneous set of indicators and metrics, or to create a cascade mechanism in which the results of a method become the input of another method. This cascade mechanism could be the designed, for example, in such a way that VSM method could be addressed to identify inflows and outflows to each process phase, while LCA, s-LCA, LCC methods could account for environmental, social, and costs impacts (respectively) associated with a product's life cycle (i.e., from cradle to grave). At the same time, EMA could have a broader reach by capitalizing on its specific characteristics in considering the global demand for resources from the biosphere, the supply side perspective, the appropriate use of resources according to their environmental quality and renewability. Moreover, Sus-VMS could receive as input the result of LCA, s-LCA, LCC methods and provide an integrated result. In this way the weaknesses and limitations mentioned above could turn into strengths of an emerging integrated framework for the selection of different methods, more focused on a circular product system to which this report aspires.

Furthermore, on the base of the literature and research analysed, this report has highlighted that additional research efforts have to be done in due main direction. The first is to sustain research efforts aimed to the integration among assessment methods. In fact, very limited research has been carried out so far on real integration among methods. A clear example is the lack of integration of VSM with other assessment tools. The second is to promote the developments of metrics, indicators, calculation models, purposefully designed to assess and understand the environmental, social and economic implications of circularity patterns in production systems. In fact, although the methods analysed show a growing tendency to consider sustainability issues from a TBL perspective, are still addressed to a linear economy perspective. They do not consider those processes that are crucial key of a circular paradigm (repair, remanufacture, resale) and that aims to extend the product lifecycle as well as reduce the resource consumption and waste generation.

To conclude, this report highlights that these methodologies, although not uniformly and with all the limitations highlighted in this report, are very poorly applied in the case of the agro-food and agriculture sectors. Further research efforts must be made in this direction considering both the great direct social and environmental economic impact of these sectors and the indirect effect that they generate through the intense system of commercial and production integrations within the supply chains and with other related sectors (e.g. chemical, packaging, distribution, transport, etc.).

5.1 Present challenges and research perspectives

This research team is committed to test the integrated framework proposed in this report by implementing it in different agro-industrial systems. As mentioned in Section 4.1, we have preliminarily applied the Life Cycle Assessment method to researches in progress to address the circular performance of the agro-food industry. In the latter the allocation procedure is still a critical issue (with the need to clearly distinguish among products, co–products and by–products), It becomes even more subjective when biorefinery patterns are considered (although we do not consider a biorefinery a new plant for concentrated conversion of selected residues, but instead a diffuse and planned process where residues are exchanged and converted in accordance with the needs of local agricultural and industrial processes). By applying solely, the LCA does not offer a comprehensive picture of the system as whole, given that relevant factors are not taken into proper consideration (among which labour, bio–resources, degree of renewability of materials, large scale infrastructures that affect the local functioning of processes). A contribute to reduce these limits is provided by the merging of LCA with EMA. This allows to enlarge the LCA focus to include the time and larger scales for resource generation and a new concept of environmental quality that includes the biosphere activity in support of technological and economic activities. Moreover, by applying eLCC it is possible to acquire the information needed to support the managerial decision-making process. Other opportunities could emerge from the integration of the above assessment methods and modelling tools (e.g. Stella or G.I.S.) in order to create scenarios for appropriate resource management, identification of consequences depending on different policies and provision of a basis for discussion among stakeholders and policy makers, as we did, for example, in a research leading to the simulation of urban household food, water and energy consumption at urban level (previously mentioned paper No. 8, Casazza et al, Section 4.1 above).

References

Ahmad S., Wong K.Y., Ahmad R., 2019, Life cycle assessment for food production and manufacturing: recent trends, global applications and future prospects, Procedia Manufacturing, 34, 49-57

Alejandrino C., Larisa, Irma, Mercante, I., María D., Bovea, M.D., 2021. Life cycle sustainability assessment: Lessons learned from case studies. Environmental Impact Assessment Review, 87: 106517.

Andrews, E. S. (2009). *Guidelines for social life cycle assessment of products: social and socio-economic LCA guidelines complementing environmental LCA and Life Cycle Costing, contributing to the full assessment of goods and services within the context of sustainable development*. UNEP/Earthprint.

Asiedu, Y., Gu, P., 1998. Product life cycle cost analysis: State of the art review. Int. J. Prod. Res. https://doi.org/10.1080/002075498193444

Benoît, C., Norris, G.A., Valdivia, S., Ciroth, A., Moberg, A., Bos, U., Prakash, S., Ugaya, C., Beck, T., 2010. The guidelines for social life cycle assessment of products: Just in time! Int. J. Life Cycle Assess. 15, 156– 163. https://doi.org/10.1007/s11367-009-0147-8

Bierer, A., Götze, U., Meynerts, L., Sygulla, R., 2015. Integrating life cycle costing and life cycle assessment using extended material flow cost accounting. J. Clean. Prod. 108, 1289–1301. https://doi.org/10.1016/j.jclepro.2014.08.036

Bocken, N.M.P., de Pauw, I., Bakker, C., van der Grinten, B., 2016. Product design and business model strategies for a circular economy. J. Ind. Prod. Eng. 33, 308–320. https://doi.org/10.1080/21681015.2016.1172124

Borza, M., 2014. Emerging Markets Queries in Finance and Business The connection between efficiency and sustainability - a theoretical approach Procedia Economics and Finance 15 (2014) 1355 – 1363.

Braglia, M., G. Carmignani & F. Zammori (2011) A new value stream mapping approach for complex production systems, International Journal of Production Research, 44:18-19, 3929-3952.

Brentrup, F., Küsters, J., Kuhlmann, H., Lammel, J., 2004. Environmental impact assessment of agricultural production systems using the life cycle assessment methodology I . Theoretical concept of a LCA method tailored to crop production 20, 247–264. https://doi.org/10.1016/S1161-0301(03)00024-8

Brown, A., J. Amundson, and F. Badurdeen, 2014. Sustainable value stream mapping (Sus-VSM) in different manufacturing system configurations: application case studies. J. Clean. Prod., 85: 164-179.

Brown, M.T., and Ulgiati, S., 2011. Understanding the global economic crisis: A biophysical perspective. Ecological Modelling, 223: 4-13.

Brown, M.T., Daniel E. Campbell, Christopher De Vilbiss, Sergio Ulgiati, 2016c. The geobiosphere emergy baseline: A synthesis, Ecological Modelling, 339: 92-95

Brown, M.T., Protano, G., and Ulgiati, S., 2011. Assessing Geobiosphere Work of Generating Global Reserves of Coal, Crude Oil, and Natural Gas. Ecological Modelling, 222(3): 879-887.

Brown, M.T., Ulgiati, S., 2004. Emergy Analysis and Environmental Accounting. Encycl. Energy 2, 329–354. https://doi.org/10.1016/B0-12-176480-X/00242-4

Brown, M.T., Ulgiati, S., 2010. Updated evaluation of exergy and emergy driving the geobiosphere: A review and refinement of the emergy baseline. Ecological Modelling, 221(20): 2501-2508.

Brown, M.T., Ulgiati, S., 2016a. Assessing the global environmental sources driving the geobiosphere: A revised emergy baseline. Ecol. Modell. 339, 126–132. https://doi.org/10.1016/J. ECOLMODEL.2016.03.017

Brown, M.T., Ulgiati, S., 2016b. Emergy assessment of global renewable sources. Ecol. Modell. 339, 148–156. https://doi.org/10.1016/j.ecolmodel.2016.03.010

Buonocore, Elvira, Mellino, Salvatore, De Angelis, Giuseppe, Liu, Gengyuan, Ulgiati, Sergio (2018). Life cycle assessment indicators of urban wastewater and sewage sludge treatment. ECOLOGICAL INDICATORS, vol. 94, p. 13-23.

Casazza M., Huisingh D., Ulgiati S., Severino V., Liu G., Lega M., 2019. Product service system-based municipal solid waste circular management platform in Campania region (Italy): A preliminary analysis. Procedia CIRP, 83: 224-229.

Casazza, M., Jingyan Xue, Shupan Du, Gengyuan Liu, Sergio Ulgiati, 2021. Simulation of scenarios for urban household water and energy consumption. PLOS ONE, 16(4 April), e0249781.

Ciroth, A., Hildenbrand, J., Steen, B., 2011. Life Cycle Costing, in: De Meester, S., Alvarenga, R. (Eds.), Sustainability Assessment of Renewables-Based Products: Methods and Case Studies. John Wiley & Sons. https://doi.org/10.1111/j.1559-3584.1969.tb05481.x

Corcelli, F., Ripa, M., Ulgiati, S., 2018. Efficiency and sustainability indicators for papermaking from virgin pulp. An emergy-based case study. Resources, Conservation and Recycling, 131: 313-328.

Corcelli, Fabiana, Fiorentino, Gabriella, Vehmas, Jarmo, Ulgiati, Sergio (2018). Energy efficiency and environmental assessment of papermaking from chemical pulp - A Finland case study. JOURNAL OF CLEANER PRODUCTION, vol. 198, p. 96-111.

Costa, D., Quinteiro, P., Dias, A.C., 2019. A systematic review of life cycle sustainability assessment: Current state, methodological challenges, and implementation issues. Sci. Total Environ. 686, 774–787. https://doi.org/10.1016/j.scitotenv.2019.05.435

De Menna, F., Loubiere, M., Dietershagen, J., Vittuari, M., Unger, N. 2016. Methodology for evaluating LCC. REFRESH Deliverable 5.2. https://eu-refresh.org/sites/default/files/REFRESH_D5_2_Meth_for_ev_LCC_Final_formatted_0.pdf

De Steur H., Wesana J., Kumar Dora M., Pearce D., Gellynck X., 2016. Applying Value Stream Mapping to reduce food losses and wastes in supply chains: A systematic review. Waste Management. 58. p.359-368.

Djatna, T., Prasetyo, D., 2019. Integration of sustainable value stream mapping (Sus. VSM) and life-cycle assessment (LCA) to improve sustainability performance. Int. J. Adv. Sci. Eng. Inf. Technol. 9, 1337– 1343. https://doi.org/10.18517/ijaseit.9.4.9302

Dreyer L.,ouise, Michael Hauschild, M., and Jens Schierbeck, J., 2006. A Framework for Social Life Cycle Impact Assessment. The International Journal of Life Cycle Assessment, 11: 88–97.

Ellen Macarthur Foundation, Towards a Circular Economy. Economic and Business Rationale for an Accelerated Transition. Ellen Macarthur Foundation; Cowes, UK: 2012.

EPA, 2011. https://www.epa.gov/sites/production/files/2013-10/documents/lean-water-toolkit.Achieving_Process_Excellence_Through_Water_Efficiency.pdf. United States Environmental Protection Agency.

Epstein, M.J., 1996. Measuring corporate environmental performance, Irwin Professional Publishing, Chicago.

European Commission, 2015. Closing the loop - An EU action plan for the Circular Economy.

European Commission, 2019. Sustainable Products in a Circular Economy - Towards an EU Product Policy Framework contributing to the Circular Economy.

European Commission, 2020. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. A new Circular Economy Action Plan - For a cleaner and more competitive Europe (COM/2020/98 final). Brussels, Belgium.

European Commission, 2021, European Platform on Life Cycle Assessment, https://eplca.jrc.ec.europa.eu/lifecycleassessment.html. (last accessed June 2021)

Faulkner, W., Badurdeen, F., 2014. Sustainable Value Stream Mapping (Sus-VSM): Methodology to visualize and assess manufacturing sustainability performance. J. Clean. Prod. 85, 8–18. https://doi.org/10.1016/j.jclepro.2014.05.042

Fiedler Katherine, Elisabeth Haub, E., Steven Lord, S. Jason J. Czarnezki, J.J., Elisabeth Haub, E., 2008. Life Cycle Costing and Food Systems: Concepts, Trends, and Challenges of Impact Valuation. Journal of Environmental & Administrative Law, 8(1).

Finkbeiner, M., Schau, E.M., Lehmann, A., Traverso, M., 2010. Towards life cycle sustainability assessment. Sustainability 2, 3309–3322. https://doi.org/10.3390/su2103309

Fiorentino, Gabriella, Zucaro, Amalia, Ulgiati, Sergio (2019). Towards an energy efficient chemistry. Switching from fossil to bio-based products in a life cycle perspective. ENERGY, vol. 170, p. 720-729.

Florio, Ciro, Fiorentino, Gabriella, Corcelli, Fabiana, Ulgiati, Sergio, Dumontet, Stefano, Güsewell, Joshua, Eltrop, Ludger (2019). A life cycle assessment of biomethane production from waste feedstock through different upgrading technologies. ENERGIES, vol. 12.

Frankl, P., and Rubik, F., 2000. Life Cycle Assessment in Industry and Business. Adoption Patterns, Applications and Implications. Springer.

Geissdoerfer, M., Savaget, P., Bocken, N.M.P., Hultink, E.J., 2017. The Circular Economy – A new sustainability paradigm? J. Clean. Prod. 143, 757–768. https://doi.org/10.1016/j.jclepro.2016.12.048

Geng, Y., Joseph Sarkis, Sergio Ulgiati, 2016. Sustainability, well-being, and the circular economy in China and worldwide. Science 6278(Supplement):73-76.

Geng, Y., Joseph Sarkis, Sergio Ulgiati, Pan Zhang, 2013. Measuring China's Circular Economy. Science, 339 (6127): 1526-1527, DOI: 10.1126/science.1227059

Ghisellini P., Ulgiati S., 2020. Circular economy transition in Italy. Achievements, perspectives and constraints. Journal of Cleaner Production, 243: 1-18.

Ghisellini, P., Protano, G., Viglia, S., Gaworski, M., Setti, M., Ulgiati, S., 2014. Integrated agricultural and dairy production within a circular economy framework. A comparison of Italian and Polish farming systems. J. Environ. Account. Manag. 2, 367–384. https://doi.org/10.5890/JEAM.2014.12.007

Ghisellini, P., Remo Santagata, Amalia Zucaro, and Sergio Ulgiati, 2019. Circular patterns of waste prevention and recovery. E3S Web of Conferences 119, 00003.

Giannetti, B.F., Agostinho, F., Moraes, L.C., Almeida, C.M.V.B., Ulgiati, S., 2015. Multicriteria cost-benefit assessment of tannery production: The need for breakthrough process alternatives beyond conventional technology optimization. Environmental Impact Assessment Review, 54, pp. 22–38.

Heijungs, R., Settanni, E., Guinée, J., 2013. Toward a computational structure for life cycle sustainability analysis: Unifying LCA and LCC. Int. J. Life Cycle Assess. 18, 1722–1733. https://doi.org/10.1007/s11367-012-0461-4

Hines, P., Rich, N., 1997. The seven value stream mapping tools. Int. J. Oper. Prod. Manag. 17, 46–64. https://doi.org/10.1108/01443579710157989

Hoogmartens, R., Van Passel, S., Van Acker, K., Dubois, M., 2014. Bridging the gap between LCA, LCC and CBA as sustainability assessment tools. Environ. Impact Assess. Rev. 48, 27–33. https://doi.org/10.1016/j.eiar.2014.05.001

Hunkeler, D., Lichtenvort, K., Rebitzer, G., 2008. Environmental Life Cycle Costing. SETAC Press.

Ingwersen WW., 2010. Uncertainty characterization for emergy values. Ecol Model., 221:445-452.

International Institute for Sustainable Development (IISD), 2009. Life Cycle Costing. A Question of Value. https://ec.europa.eu/environment/gpp/pdf/WP-LifeCycleCosting.qx.pdf. Pp. 1–28.

Iotti M.attia and Giuseppe Bonazzi G.„ 2014. The application of life cycle cost (LCC) approach to quality food production: A comparative analysis in the Parma PDO HAM sector. American Journal of Applied Sciences, 11(9): 1492-1506.

Iraldo, F., Facheris, C., Nucci, B., 2017. Is product durability better for environment and for economic efficiency? A comparative assessment applying LCA and LCC to two energy-intensive products. J. Clean. Prod. 140, 1353–1364. https://doi.org/10.1016/j.jclepro.2016.10.017.

ISO, 2006a. ISO 14040: Environmental management–life cycle assessment—Principles and framework. Int. Organ. Stand.

ISO, 2006b. ISO 14044. Environ. Manag. - Life cycle assessement - Requir. Guidel. ISO 14044, Int. Organ. Stand. https://doi.org/10.1007/s11367-011-0297-3

Jacquemin, L., Pontalier, PY., Sablayrolles, C., 2012. Life cycle assessment (LCA) applied to the process industry: a review. Int J Life Cycle Assess 17, 1028–1041.

Jones, D., 1995. "Applying Toyota principles to distribution", Supply Chain Development Programme I, Workshop #8 Workbook, Britvic Soft Drinks Ltd, Lutterworth, 6-7 July 1995.

Kloepffer, W., 2008. Life cycle sustainability assessment of products (with Comments by Helias A. Udo de Haes, p. 95). Int. J. Life Cycle Assess. 13, 89–94. https://doi.org/10.1065/lca2008.02.376

Korpi, E., Ala-Risku, T., 2008. Life cycle costing: A review of published case studies. Manag. Audit. J. 23, 240– 261. https://doi.org/10.1108/02686900810857703

Lieder, M., Rashid, A., 2016. Towards circular economy implementation: a comprehensive review in context of manufacturing industry. J. Clean. Prod. 115, 36–51. https://doi.org/10.1016/j.jclepro.2015.12.042
Linder, M., Sarasini, S., van Loon, P., 2017. A Metric for Quantifying Product-Level Circularity. J. Ind. Ecol. 21, 545–558. https://doi.org/10.1111/jiec.12552
Liu G., Casazza M., Hao Y., Zhang Y., Ulgiati S., 2019. Emergy analysis of urban domestic water metabolism: A case study in Beijing (China). Journal of Cleaner Production, 234: 714-724.
Liu, GY, Hao, Y., Dong, L., Yang, ZF, Zhang, Y., Ulgiati, S., 2017. An emergy-LCA analysis of municipal solid waste management. Resources, Conservation and Recycling, 120: 131-143.
Martinez, S., Delgado, M. del M., Martinez Marin, R., Alvarez, S., 2019. Organization Environmental Footprint through Input-Output Analysis: A Case Study in the Construction Sector. J. Ind. Ecol. https://doi.org/10.1111/jiec.12827
Marvuglia, A., Santagata, R., Rugani, B., Benetto, E., 2018. Emergy-based indicators to measure circularity : promises and problems Emergy-based indicators to measure circularity : promises and problems. ENERGY POLICY J. 21, 176–196. https://doi.org/10.24425/124510
Møller F., Slentø E., Frederiksen P., 2014, Integrated well-to-wheel assessment of biofuels combining energy and emission LCA and welfare economic cost benefit analysis. Biomass Bioenergy 60, 41–49.
Monden, Y., 1994, Toyota Production System. An Integrated Approach to Just-In-Time, Springer.
Ncube, A., Fiorentino, G., Colella, M., Ulgiati, S., 2021. Upgrading wineries to biorefineries within a Circular Economy perspective: An Italian case study. Science of the Total Environment, 775: 145809.
Niero, M., Kalbar, P.P., 2019. Coupling material circularity indicators and life cycle based indicators: A proposal to advance the assessment of circular economy strategies at the product level. Resour. Conserv. Recycl. https://doi.org/10.1016/j.resconrec.2018.10.002
Norris, G.A., 2001. Integrating life cycle cost analysis and LCA. Int. J. Life Cycle Assess. 6, 118–120. https://doi.org/10.1007/BF02977849
Norton, A. and A. Fearne, 2009. Sustainable value stream mapping in the food industry. In: Woodhead Publishing Series in Food Science, Technology and Nutrition, Handbook of Waste Management and Co-Product Recovery in Food Processing, Editor(s): Keith Waldron, Woodhead Publishing. pPp. 3-22,
Notarnicola, B., Salomone, R., Petti, L., Renzulli, P.A., Roma, R., Cerutti, A.K. (Eds.), 2015. Life Cycle Assessment in the Agri-food Sector. Case Studies, Methodological Issues and Best Practices. Springer.
O'Brien, M., Doig, A., Clift, R., 1996. Social and environmental life cycle assessment (SELCA): Approach and methodological development. Int. J. Life Cycle Assess. 1, 231–237. https://doi.org/10.1007/BF02978703
Odum, H.T., 1994. Ecological and general systems : an introduction to systems ecology.
Odum, H.T., 1996. Environmental accounting. Emergy and Environmental Decision Making. John Wiley Sons, INC 370. https://doi.org/10.1017/CBO9781107415324.004
Oliveira, M., Annalisa Cocozza, Amalia Zucaro, Remo Santagata, Sergio Ulgiati, 2021. Circular economy in the agro-industry: Integrated environmental assessment of dairy products. Renewable and Sustainable Energy Reviews, 148: 111314.
Oliveira, M., Miguel, M., van Langen, S.K., Ncube, A., Zucaro, A., Fiorentino, G., Passaro, R., Santagata, R., Coleman, N., Lowe, B.H., Ulgiati, S., Genovese, A., 2021a. Circular Economy and the Transition to a Sustainable Society: Integrated Assessment Methods for a New Paradigm. Circ. Econ. Sustain. https://doi.org/10.1007/s43615-021-00019-y

Paju M, Heilala J, Hentula M, Heikkila A, Johansson B, Leong S, Lyons K (2010) "*Framework and indicators for a sustainable manufacturing mapping methodology*". In: Proceedings of the 2010 winter simulation conference (WSC), Phoenix, Arizona, USA. IEEE, pp 3411–3422.
Pauliuk, S., 2018. Critical appraisal of the circular economy standard BS 8001:2017 and a dashboard of quantitative system indicators for its implementation in organizations. Resour. Conserv. Recycl. 129, 81–92. https://doi.org/10.1016/j.resconrec.2017.10.019
Pelletier, N., 2014. Life Cycle Assessment in agriculture. Potential Applications, Social License and Market Access. Prepared for Alberta Agriculture and Forestry, Canada.
Peña, A., M. Rosa Rovira-Val, M.R., 2020. A longitudinal literature review of life cycle costing applied to urban agriculture. The International Journal of Life Cycle Assessment, 25: 1418–1435.
Gluch Pernilla, G., and Henrikke Baumann, H., 2004. The life cycle costing (LCC) approach: a conceptual discussion of its usefulness for environmental decision-making. Building and Environment, 39: 571-580.
Petti, L., Serreli, M., Di Cesare, S., 2018. Systematic literature review in social life cycle assessment. Int. J. Life Cycle Assess. 23, 422–431. https://doi.org/10.1007/s11367-016-1135-4
Pollaro, N., Remo Santagata, Sergio Ulgiati, 2020. Sustainability Evaluation of Sheep and Goat Rearing in Southern Italy. A Life Cycle Cost/Benefit Assessment. Journal of Environmental Accounting and Management 8(3): 229-242.
Raugei, M., Rugani, B., Benetto, E., Ingwersen, W.W., 2014. Integrating emergy into LCA: Potential added value and lingering obstacles. Ecol. Modell. 271, 4–9. https://doi.org/10.1016/j.ecolmodel.2012.11.025
Ridolfi, R., Pulselli, F.M., Morandi, F., Oliveira, M., Bastianoni, S., 2018. Emergy and Sustainability ☆, in: Reference Module in Earth Systems and Environmental Sciences. Elsevier. https://doi.org/10.1016/B978-0-12-409548-9.00590-X
Ripa, M., Fiorentino, G., Giani, H., Clausen, A., Ulgiati, S., 2017. Refuse recovered biomass fuel from municipal solid waste. A life cycle assessment. Applied Energy, 186(2): 211-225.
Ripa, M., Fiorentino, G., Vacca, V., Ulgiati, S., 2017. The relevance of site–specific data in Life Cycle Assessment (LCA). The case of the municipal solid waste management in the metropolitan city of Naples (Italy), Journal of Cleaner Production, 142: 445-460
Rotolo, G. C., Francis, C. A., Ulgiati, S., 2018. Environmentally sound resource valuation for a more sustainable international trade: Case of argentine maize. Resources, Conservation and Recycling, 131: 271-282.
Rufis Fregue Tagne Tiegam, Donald Raoul Tchuifon Tchuifon, Remo Santagata, Paul Alain Kouteu Nanssou, Solomon Gabche Anagho, Ioana Ionel, Sergio Ulgiati, 2021. Optimization by response surface methodology of the production of activated carbon from cocoa pod and life cycle assessment. Journal of Cleaner Production, 288, 125464.
Sala S., Reale F., Cristobal-Garcia J., Marelli L., Pant R., 2016. Life cycle assessment for the impact assessment of policies, EUR 28380 EN; doi:10.2788/318544
Sala, S., Farioli, F., Zamagni, A., 2013. Life cycle sustainability assessment in the context of sustainability science progress (part 2). Int. J. Life Cycle Assess. 18, 1686–1697. https://doi.org/10.1007/s11367-012-0509-5
Santagata R., Zucaro A., Fiorentino G., Lucagnano E., Ulgiati S., 2020. Developing a procedure for the integration of Life Cycle Assessment and Emergy Accounting approaches. The Amalfi paper case study. Ecological Indicators, 117: 106676.
Santagata R., Zucaro A., Viglia S., Ripa M., Tian X., Ulgiati S., 2020. Assessing the sustainability of urban eco-systems through Emergy-based circular economy indicators. Ecological Indicators, 109: 105859.

Santagata, R., Ripa, M., Ulgiati, S., 2017. An environmental assessment of electricity production from slaughterhouse residues. Linking urban, industrial and waste management systems, Applied Energy, 186: 175-188

Santagata, R., Viglia, S., Fiorentino, G., Liu, G., Ripa, M., 2019. Power generation from slaughterhouse waste materials. An Emergy Accounting assessment. J. Clean. Prod. 223, 536–552. https://doi.org/https://doi.org/10.1016/j.jclepro.2019.03.148

Santagata, R., Zucaro, A., Viglia, S., Ripa, M., Tian, X., Ulgiati, S., 2020b. Assessing the sustainability of urban eco-systems through Emergy-based circular economy indicators. Ecol. Indic. 109, 105859. https://doi.org/10.1016/j.ecolind.2019.105859.

Savić Bojan, Milojević Ivan, Petrović Vesna, 2019. Cost optimization in agribusiness based on life cycle costing. Ekonomika poljoprivrede, 66(3): 823-834.

Serrano Lasa, I., Ochoa Laburu, C. and de Castro Vila, R.Serrano Lasa Ibon, Carlos Ochoa Laburu, Rodolfo de Castro Vila, 2008. An evaluation of the value stream mapping tool. Business Process Management Journal, 14(1): 39-52.

Settanni, E., B. Notarnicola, G. Tassielli, 2010. Combining Life Cycle Assessment of food products with economic tools. In: U. Sonesson, J. Berlin and F. Ziegler (Eds). Environmental Assessment and Management in the Food Industry. Life Cycle Assessment and Related Approaches. Woodhead Publishing Series in Food Science, Technology and Nutrition. Pages 207-218.

Simons D, Mason R (2002) "Environmental and transport supply chain evaluation with sustainable value stream mapping". In: Proceedings of the 7th logistics research network conference, Birmingham.

Singh, B. and Sharma, S.K., 2009. "Value stream mapping as a versatile tool for lean implementation: an Indian case study of a manufacturing firm", *Measuring Business Excellence*, 13(3): 58-68. https://doi.org/10.1108/13683040910984338

Skovgaard M, Ibenholt K, Ekvall T (2007) Nordic guideline for cost-benefit analysis of waste management. Nordic cooperation. Nordic Council of Ministers, Denmark. https://www.norden.org/en/publication/nordic-guidelines-cost-benefit-analysis, Last accessed May, 20121.

Sparks. D.T., Combining Sustainable Value Stream Mapping and Simulation To Assess Manufacturing Supply Chain Network Performance., Thesis and Dissertations University of Kentucky U Knowledge, 2014

STAR-ProBio, 2019. STAR-ProBio Deliverable D6.3, Criteria and indicators developed for conducting S-LCA impact assessment.

Stillitano, T.; Spada, E.; Iofrida, N.; Falcone, G.; De Luca, A.I., 2021. Sustainable Agri-Food Processes and Circular Economy Pathways in a Life Cycle Perspective: State of the Art of Applicative Research. Sustainability, 13, 2472.

Suárez Barraza, ManuelM., Miguel-Dávila, J.,osé, Vásquez, F.,abiola, 2011. Supply chain value stream mapping: a new tool of operation management. International Journal of Quality & Reliability Management, 33(4): 518-534.

Swarr, T.E., Hunkeler, D., Klöpffer, W., Pesonen, H.L., Ciroth, A., Brent, A.C., Pagan, R., 2011. Environmental life-cycle costing: A code of practice. Int. J. Life Cycle Assess. 16, 389–391. https://doi.org/10.1007/s11367-011-0287-5

Theide S., W. Li W., , S. Kara S., C. Herrmann C., , 2016. Integrated analysis of energy, material and time flows in manufacturing systems. Procedia CIRP, 48 (2016), pp. 200-205

Thomas, M., 2011. Life Cycle Assessment and the New Zealand Wine Industry : A tool to support continuous environmental improvement.

Ulgiati, S., Brown, M.T., 2014. Labor and Services as Information Carriers in Emergy-LCA Accounting. Environmental Accounting and Management 2(2): 163-170.

Ulgiati, S., Franzese, P.P., Zucaro, A., Fiorentino, G., Santagata, R., Corcelli, F., Rallo, R.F., Casazza, M., 2018. Report. Standardization and integration of assessment methods focused on energy efficiency. Deliverable 3.4. European Futures of Energy Efficiency (EUFORIE). http://www.euforie-h2020.eu.

UNEP, SETAC, 2013. The Methodological Sheets for Sub-categories in Social Life Cycle Assessment (S-LCA).

Valsasina L., Pizzol M., Smetana S., Georget E., Mathys A., Heinz V., 2016. Life cycle assessment of emerging technologies: The case of milk ultra-high pressure homogenisation, Journal of Cleaner Production, 142, 2209-2217

van Haaster, B., Ciroth, A., Fontes, J., Wood, R., Ramirez, A., 2017. Development of a methodological framework for social life-cycle assessment of novel technologies. Int. J. Life Cycle Assess. 22, 423–440. https://doi.org/10.1007/s11367-016-1162-1

Verma, N. and Sharma, V., 2016. Energy Value Stream Mapping a Tool to Develop Green Manufacturing. Procedia Engineering 149:526-534.

Vidergar P., Perc M., Kovačič Lukmana R., 2021, A survey of the life cycle assessment of food supply chains, Journal of Cleaner Production, Vol.286, 125506

Vinodh, S., Ben Ruben, R., Asokan, P., 2016. Life cycle assessment integrated value stream mapping framework to ensure sustainable manufacturing: A case study. Clean Technol. Environ. Policy 18, 279–295. https://doi.org/10.1007/s10098-015-1016-8

Vinyes E., Asin L., Alegre S., Muñoz P., Boschmonart J., Gasol C., 2017, Life Cycle Assessment of apple and peach production, distribution and consumption in Mediterranean fruit sector. Journal of Cleaner Production, 149, 313-320

White, G.E., Ostwald, P.F., 1976. Life cycle costing. Manag. Account. 15, 335–44.

Woehrle, S. L., & Abou-Shady, L. (2010). Using Dynamic Value Stream Mapping And Lean Accounting Box Scores To Support Lean Implementation. *American Journal of Business Education (AJBE)*, *3*(8), 67-76.

Zamagni, A., Feschet, P., De Luca, A.I., Iofrida, N., Buttol, P., 2015. Social Life Cycle Assessment. Sustain. Assess. Renewables-Based Prod. 229–240. https://doi.org/10.1002/9781118933916.ch15