
XI Convegno dell'Associazione Rete Italiana LCA

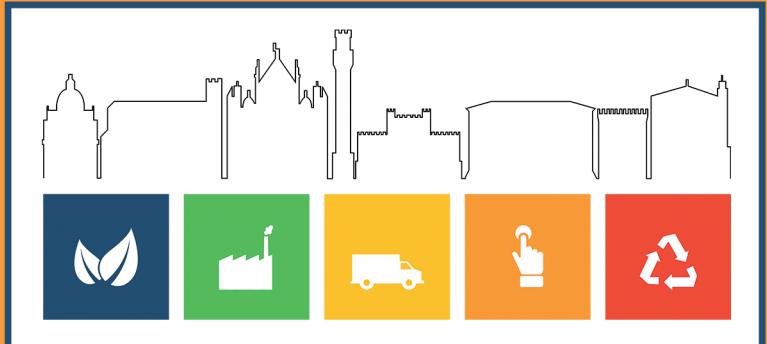
Resource Efficiency e Sustainable Development Goals: il ruolo del Life Cycle Thinking

Siena
22 – 23 giugno 2017

a cura di Valentina Niccolucci, Arianna Dominici Loprieno,
Simone Maranghi, Simona Scalbi



Agenzia nazionale per le nuove tecnologie,
l'energia e lo sviluppo economico sostenibile



Atti del XI Convegno dell'Associazione Rete Italiana LCA

Resource Efficiency e Sustainable Development Goals: il ruolo del Life Cycle Thinking

Siena, 22-23 giugno 2017

A cura di Valentina Niccolucci, Arianna Dominici Loprieno, Simone Maranghi, Simona Scalbi

Immagini del volume a cura di Paola Sposato

2017 ENEA

Agenzia nazionale per le nuove tecnologie, l'energia e
lo sviluppo economico sostenibile

ISBN: 978-88-8286-352-4

Revisione editoriale: Giuliano Ghisu

Copertina: Cristina Lanari

SOMMARIO

COMITATO SCIENTIFICO

i

COMITATO ORGANIZZATORE

iii

PREFAZIONE

iv

PRESENTAZIONI ORALI

1

SESSIONE I: RESOURCE EFFICIENCY E LIFE CYCLE THINKING

1

Assessment of resource efficiency in a life cycle perspective: the case of reuse
F. ARDENTE, P. TECCHIO, S. BOBBA, F. MATHIEUX

2

SESSIONE II: LIFE CYCLE SUSTAINABILITY ASSESSMENT, ECONOMIC GROWTH AND SUSTAINABLE DEVELOPMENT GOALS

10

Which role for Life Cycle Thinking in the definition of meaningful indicators for the circular economy?

11

M. NIERO, M.Z. HAUSCHILD

Biomass for biofuel production: a sustainability assessment by means of LCA and energy

20

F. SALADINI, N. PATRIZI, F.M. PULSELLI, S. BASTIANONI

Life cycle assessment of a charging station for electric bicycles

G. MONDELLO, R. SALOMONE, L. GIUTTARI

29

<i>Valutazione LCA per la minimizzazione dell'impatto ambientale nello sfruttamento della risorsa geotermica</i>	38
M.L. PARISI, M. BRAVI, M.C. BARATTO, R. BASOSI	
<i>Analisi del ciclo di vita del laterizio: un caso studio in Piemonte</i>	
C. CARBONARO, F. THIEBAT	47
<i>Life cycle assessment of rare earth elements production: case study from a monazite-based in Brazil</i>	
F.M. DA R. DE S. LIMA, G.A. LOVÓN-CANCHUMANI, L.M. TARAZONA ALVARADO, M. SERRA SAMPAIO	55
<i>Analisi del ciclo di vita e Product Category Rules di prodotti emoderivati</i>	
E. NERI, R.M. PULSELLI, B. RUGANI, M. MARCHI, M. BONALDI	64
<i>Life cycle assessment of a novel polyhydroxyalkanoates production process with mixed microbial cultures fed on winery waste</i>	
L. VOGLI, S. RIGHI, S. MACRELLI, P. GALLETTI, C. SAMORÌ, R. CONTI, C. TORRI, E. TAGLIAVINI	72
<u>SESSIONE III: SVILUPPI METODOLOGICI DI LCA, LCC E SLCA E INTEGRAZIONE CON ALTRI STRUMENTI PER STUDI DI SOSTENIBILITÀ</u>	80
<i>Organisational LCA for supporting environmental management towards sustainability of production patterns: the case of agricultural machinery</i>	
S. D'ANGELO, G. GARAVINI, E. BREDA, S. RIGHI, M. QUARANTA, A. ZAMAGNI	81
<i>The uncertainty analysis in LCA studies: state of the art</i>	
A. MAZZI, M. MASON, S. TONIOLI, F. MARZOTTO, A. SCIPIONI	89
<i>Social Life Cycle Assessment of a textile product</i>	
P. LENZO, M. TRAVERSO, R. SALOMONE, G. IOPPOLO	98
<i>Social Life Cycle Assessment per il settore lattiero caseario: focus sulla comunità locale</i>	
I. MASSA, M.C. LUCCHETTI, G. ARCESE, O. MARTUCCI	109

SESSIONE IV: WATER - FOOD - ENERGY - WASTE	116
<i>Il prolungamento della shelf-life come strategia di mitigazione dell'impatto nelle filiere agro-alimentari: il caso studio del grissino integrale</i>	117
J. BACENETTI, V. GIOVENZANA, M. NIERO, C. INGRAO, R. GUIDETTI	
<i>Life Cycle Assessment applicata alla Provolone delle Madonie</i>	125
M. CELLURA, M. A. CUSENZA, S. LONGO, F. GUARINO, M. MISTRETTA	
<i>Structure and pattern of food consumption in Italian household: an analysis of impact on climate change and land use</i>	133
A. K. CERUTTI, S. SALA, A. PIETTA, M. SECCHI	
<i>Valutazione dei potenziali impatti ambientali legati a due opzioni di trattamento dei rifiuti organici in Abruzzo</i>	142
E. MANCINI, I. ARZOUUMANIDIS, A. RAGGI	
<i>Evaluating exposure to pesticides in banana production systems: an expert elicitation approach</i>	150
S. DI CESARE, C. MACOMBE, S. GRIMBUHLER, L. PETTI, D. LOEILLET	
<i>Improving resource efficiency in the cultivation of bread wheat through precision agriculture</i>	159
R. VILLANI, S. BOSCO, F. DRAGONI, M. RUGGERI, P. MERIGGI, C. TOZZINI, G. RAGAGLINI	
<i>Substitution of energy crops with bio-waste in an existing anaerobic digestion plant: an environmental and energetic analysis</i>	166
F. DI MARIA, F. SISANI, M. LASAGNI	
<i>Can renewable energy sources improve the environmental performances of microalgae oil production system?</i>	175
S. JEZ, D. SPINELLI, A. FIERRO, M. ARESTA, A. DIBENEDETTO, E. BUSI, R. BASOSI	
<i>Diesel, benzina ed elettrica – un confronto sul ciclo di vita dall'utilitaria alla familiare</i>	182
P. GIRARDI, C. BRAMBILLA	
<i>Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) applied to an innovative agri-food production practice: the aquaponics. A case study in the WWF Oasis of Valle Averto (Veneto, Italy)</i>	191
A. A. FORCHINO, E. CANNARSA, S. MAILOLO, D. BRIGOLIN, R. PASTRES	

<i>Evaluating the variability of life cycle inventories of primary tillage via different operational parameters</i>	198
S.H. MOUSAVI-AVVAL, G. TASSIELLI, P.A. RENZULLI, B. NOTARNICOLA	
<u>SESSIONE V: PEF e OEF - ESPERIENZE APPLICATIVE E POSSIBILI UTILIZZI NELLE POLITICHE AMBIENTALI</u>	207
<i>Implementing life-cycle approaches and tools: experiences and learnings from Aptar Italia</i>	208
M. DEL GROSSO, A. SIMBOLI, A. RAGGI, N. CUTARELLA	
<i>Valutazione del profilo ambientale di un sistema di trattamento di rifiuti con un approccio tipo Organisation Environmental Footprint</i>	217
B. NOTARNICOLA, P. A. RENZULLI, G. TASSIELLI, G. FEDELE	
<i>Product Environmental Footprint and the wine sector: a recent case study</i>	226
D. TONON, A. ZAMAGNI, G. GARAVINI, L. CHIUSANO, P. MASONI	
POSTER	235
<i>Life Cycle datasets of the Italian stone production chain</i>	236
I. BIANCO, G. A. BLENGINI	
<i>LCA methodology on solar radiation influx control strategies in buildings: a review</i>	244
J. D. BLANCO CADENA, M. LAVAGNA, T. POLI	
<i>Water Footprint Assessment vs Life Cycle Assessment: how spatiotemporal variation could influence impact assessments</i>	253
D. D. CHIARELLI, F. RECANATI, P. MELIÀ, M. C. RULLI	
<i>LCA, raccolta dati di inventario e fasi del ciclo di vita degli edifici</i>	262
A. DALLA VALLE, M. LAVAGNA, A. CAMPIOLI	
<i>An integrated framework for the assessment of life cycle costs and environmental impacts of food waste</i>	271
F. DE MENNA, J. DAVIS, K. ÖSTERGREN, N. UNGER, M. LOUBIERE, M. VITTUARI	

La Social Life Cycle Assessment a supporto del Supply Chain Management

M. D'EUSANIO, A. ZAMAGNI, L. PETTI

279

LCA di prodotto-servizio: il caso di studio di un lavamoto automatico

G. DOTElli, E. VIGANÒ

288

Applicazione della Water Footprint sviluppata dal WF Network: il caso del Pomodorino del Piennolo del Vesuvio DOP

M. FERRARA, V. FANTIN, S. RIGHI, C. CHIAVETTA, P. BUTTOL, A. BONOLI

297

Analisi preliminare ambientale della produzione di nanofibre tramite electrospinning

P. FRONTERA, F. PANTÒ, A. MALARA, S. SANTANGELO, P. ANTONUCCI

305

Benchmark LCA e uso di EPD nei Green Building Rating System

S. GANASSALI, M. LAVAGNA, A. CAMPIOLI

312

Impronta idrica della produzione elettrica da cicli combinati a gas naturale in Italia

A. GARGIULO

321

Procedure di allocazione nella metodologia LCA e tendenze settoriali verso un'economia circolare

S. GIORGI, M. LAVAGNA, A. CAMPIOLI

330

Produzione di latte e impatto ambientale: effetto del sistema colturale e della razione somministrata alle bovine

G. GISLON, L. BAVA, J. BACENETTI, A. TAMBURINI, M. ZUCALI, A. SANDRUCCI

339

Choosing the LCA impact categories for the building sector

A. INVIDIATA, M. LAVAGNA, E. GHISI

348

Un nuovo approccio per la valutazione del consumo e dell'impatto ambientale sulla risorsa idrica nei sistemi agricoli

D. LOVARELLI, J. BACENETTI

356

Sviluppo di un approccio integrato per la valutazione ambientale di sistemi fotovoltaici di nuova generazione: le perovskiti

S. MARANGHI, M. L. PARISI, A. SINICROPI, R. BASOSI

364

<i>Self cleaning nano-technology application on a new antibacterial insect screen: an attributional LCA study for quantifying energy and water savings</i>	373
S. MARANGHI, F. BORGHETTI, R. BASOSI, E. BUSI	
<i>L'impronta carbonica delle organizzazioni: confronto tra due micro-birrifici italiani</i>	380
P. MASOTTI, E. GIORGI, B. CAMPISI, P. BOGONI	
<i>Energy resource-based life cycle analysis of solidoxide fuel-cell power systems</i>	389
A. MEHMETI, C. BOIGUES MUÑOZ, S.J. MCPHAIL	
<i>La valutazione LCA nell'ambito del progetto cluster P.RE.MURA.</i>	397
A. MELONI	
<i>City Environmental Footprint – a framework in support of urban sustainability and Sustainable Development Goals</i>	405
N. MIRABELLA, K. ALLACKER	
<i>A review of industrial sustainability indicators for Life Cycle Sustainability Assessment</i>	414
A. NERI, P. MELIÀ, E. CAGNO, A. TRIANNI	
<i>Studio di fattibilità della valorizzazione energetica di residui agro-industriali attraverso fermentazione anaerobica (biogas)</i>	423
E. NERI, F. PASSARINI, M. BRIANI, I. VASSURA, U. MENCHERINI	
<i>Stima ex-ante della Carbon Footprint del Convegno annuale della Rete Italiana LCA 17: una proposta per il futuro</i>	430
E. NERI, N. PATRIZI, N. MARCHETTINI, S. BASTIANONI	
<i>Aumentare la consapevolezza nel consumatore può indurre un cambiamento nelle abitudini alimentari? Un progetto dell'Università di Siena sui fontanelli per la distribuzione di acqua potabile</i>	439
V. NICCOLUCCI, M. MOZZILLO, M. L. PARISI, R. BASOSI, S. BASTIANONI	
<i>Valutazione del profilo ambientale di un sistema di trattamento di rifiuti con un approccio tipo Organisation Environmental Footprint</i>	447
B. NOTARNICOLA, P. A RENZULLI, G. TASSIELLI, G. FEDELE	
<i>Water Footprint analysis (ISO 14046) of organic Chianti wine production in Tuscany, Italy</i>	455
T. PACETTI, G. CASTELLI, L. ZANCHI	

<i>Tecnological breakthrough for energy efficiency in dyes production: bio-synthetic pathway versus chemical process</i>	463
M. L. PARISI, R. POGNI, R. BASOSI	
<i>LCA application in telecommunication service industries: a literature review</i>	471
M. PAVLOVIC, L. RIGAMONTI	
<i>Sustainability assessment of the restoration of a historical building focusing on the installation of innovative building nanomaterials</i>	480
M. PINI, P. NERI, D. SETTEMBRE BLUNDO, A. M. FERRARI	
<i>Microalgae cultivation in wastewaters for energy purposes: a life-cycle based comparison</i>	489
S. ROSSI, L. RIGAMONTI	
<i>Carbon footprint performance of public school lunch menu provided by an Italian catering company</i>	498
M. SIMONETTO, C. PIERETTO, A. MANZARDO, L. CAMMISA, M.L. PUTIN, A. SCIPIONI	
<i>Analisi di sostenibilità del sistema di gestione dei rifiuti solidi in Baalbek (Libano)</i>	504
R. SPINELLI, A.M. FERRARI, P. NERI, A. BONOLI	
<i>Life Cycle and Life Cycle Assessment within International Standards</i>	513
S. TONILO, A. MAZZI, F. FORTUNA, A. SCIPIONI	
<i>The environmental profile of Pecorino Romano PDO. A case study</i>	521
E. VAGNONI, A. FRANCA, C. PORQUEDDU, P. DUCE	
<i>Social hotspots of nanocellulose production</i>	530
C. VALENTE, A. BREKKE	
<i>Produzione industriale di acido tereftalico: analisi del ciclo di vita di vie alternative da fonti rinnovabili</i>	538
M. VOLANTI, F. PASSARINI, D. CESPI, E. NERI, F. CAVANI	
<i>La sostenibilità nel restauro architettonico: valutazione comparativa delle tecniche di pulitura mediante analisi LCA</i>	546
L. VOLPI, R. SPINELLI, E. FRANZONI, A. BONOLI	

<i>The role of Life Cycle Assessment (LCA) and energy efficiency optimization during the early stage of building design</i>	554
S. ZHAO, M. LAVAGNA, E. DE ANGELIS	
<i>Succinic acid from giant reed feedstock: greenhouse gas emissions and non-renewable energy use</i>	564
A. ZUCARO, A. FORTE, A. FIERRO	
PREMIO GIOVANI RICERCATORI	573
<u>1^ classificato</u>	
<i>Packaging solutions for food waste prevention: a methodological framework for LCA-modelling</i>	574
S. NESSI, L. RIGAMONTI, M. GROSSO	
<u>2^ classificato</u>	
<i>Life Cycle Sustainability Assessment advancements in the automotive lightweight design</i>	583
L. ZANCHI, A. ZAMAGNI, M. DELOGU, M. PIERINI	
<u>3^ classificato</u>	
<i>Life cycle assessment of shale gas in the UK</i>	592
C. TAGLIAFERRI, P. LETTIERI, C. CHAPMAN	

Comitato Scientifico

Michela Aresta

Consorzio Interuniversitario Nazionale per la Reattività Chimica e la Catalisi (CIRCC)

Grazia Barberio

ENEA, Dipartimento Sostenibilità dei Sistemi Produttivi e Territoriali, Laboratorio Valorizzazione delle risorse nei sistemi produttivi e territoriali (SSPT-USER-RISE)

Simone Bastianoni

Università degli Studi di Siena, Dipartimento di Scienze Fisiche, della Terra e dell'Ambiente (DSFTA)

Maurizio Cellura

Università degli Studi di Palermo, Dipartimento di energia, ingegneria dell'informazione e modelli matematici (DEIM)

Vito D'Incognito

Take Care International, Milano

Arianna Dominici Loprieno

ENEA, Dipartimento Sostenibilità dei Sistemi Produttivi e Territoriali

Monica Lavagna

Politecnico di Milano, Dipartimento di Architettura, Ingegneria delle Costruzioni e Ambiente Costruito (ABC)

Paolo Masoni

ENEA, Dipartimento Sostenibilità dei Sistemi Produttivi e Territoriali

Anna Mazzi

Università degli Studi di Padova, Dipartimento di Ingegneria Industriale, Centro Studi Qualità Ambiente (CESQA)

Marina Mistretta

Università Mediterranea di Reggio Calabria, Dipartimento Patrimonio, Architettura, Urbanistica (PAU)

Bruno Notarnicola

Università degli Studi di Bari Aldo Moro, Dipartimento Jonico

Maria Laura Parisi

Università degli Studi di Siena, Dipartimento di Biotecnologie, Chimica e Farmacia (DBCF)

Andrea Raggi

Università degli Studi "G. d'Annunzio" di Chieti-Pescara, Dipartimento di Economia (DEc)

Lucia Rigamonti

Politecnico di Milano, Dipartimento di Ingegneria Civile e Ambientale (DICA)

Serena Righi

Università di Bologna, Campus di Ravenna, Dipartimento di Fisica e Astronomia (DIFA) e Centro Interdipartimentale di Ricerca per le Scienze Ambientali (CIRSA)

Roberta Salomone

Università degli Studi di Messina, Dipartimento di Economia

Simona Scalbi

ENEA, Dipartimento Sostenibilità dei Sistemi Produttivi e Territoriali, Laboratorio Valorizzazione delle risorse nei sistemi produttivi e territoriali (SSPT-USER-RISE)

Antonio Scipioni

Università degli Studi di Padova, Dipartimento di Ingegneria Industriale, Centro Studi Qualità Ambiente (CESQA)

Alessandra Zamagni

Ecoinnovazione srl, spin-off ENEA, Padova

An integrated framework for the assessment of life cycle costs and environmental impacts of food waste

Fabio De Menna^{1*}, Jennifer Davis², Karin Östergren², Nicole Unger³,
Marion Loubiere⁴, Matteo Vittuari¹

¹Department of Agricultural and Food Sciences, University of Bologna, Bologna,
Italy

²Rise Agrifood and Bioscience, Göteborg, Sweden

³Institute of Waste Management, University of Natural Resources and Life Sciences
(BOKU), Vienna, Austria

⁴Deloitte Sustainability, Paris, France

Email*: fabio.demenna2@unibo.it

Abstract

Food waste prevention and valorization are needed to reduce environmental and economic costs of food systems. However, these measures will have different environmental and economic effects and tradeoffs. Therefore, a consistent and integrated life cycle framework is needed to generate reliable information for both individual stakeholders and policy makers. Within the H2020 project REFRESH (Resource Efficient Food and dRink for the Entire Supply cHain), this study aimed to provide practitioners with guidance on how to combine Life Cycle Assessment (LCA) and Life Cycle Costing (E-LCC) methodologies, with a focus on the impact of food waste, its prevention, and valorization. Building on existing standards, protocols and scientific literature, a framework, consisting of methodologically structured recommendations was developed for clearly defined assessment situations. The framework is composed of a section on study purpose definition, three decision trees - on assessment situation(s), costing approach, and type of study (footprint vs. intervention) - and two sets of recommendations. The framework will be tested in the next phase of the project on selected food chain side flows.

1. Introduction

Global estimates (FAO 2011) suggest that about one third of edible food produced is lost or wasted along the supply chain. This inefficiency causes wastage of natural and economic resources. FAO estimated the cost of food wastage at US\$940 billion (FAO 2013, 2014). Food waste prevention would thus allow for saving these resources, potentially feeding more people, and reducing environmental pressure from the food system (e.g. FAO 2013, Kummu et al., 2012, Vittuari et al. 2016).

Due to the magnitude and urgency of addressing food waste, the United Nations included in the Sustainable Development Goals (SDG) a target (SDG12.3) to halve per capita global food waste at the retail and consumer level and to reduce losses along production and supply chains. In addition, the European Commission aligned itself to the UN target in its Circular Economy package, which has food waste as one of five focus waste streams and contains measures aimed at the reduction and reuse of food waste, from production to consumption and end of life (European Commission, 2015).

The transformations required for preventing and valorizing food waste will have their own economic and environmental impacts. Private and public decision makers thus will need robust, consistent and science-based approaches to inform their interventions. Life cycle approaches - such as Life Cycle Assessment LCA (ISO, 2016; EC, 2010) and Life Cycle Costing (LCC) (e.g. Hunkeler et al., 2008) - are often suggested as useful tools to analyze both the economic and environmental impacts of waste prevention, valorization, and management. By allowing comparative analysis within or across the waste hierarchy, the combined use of LCA and LCC approaches can ensure a better understanding of the impact of specific interventions, as suggested also by the EC directive on waste (EC, 2008, paragraph 4).

Life cycle assessment (LCA) is well established in studying environmental impacts of food waste (FW), but no systemic approach for practitioners has been developed to date (Corrado et al., 2017; Gruber et al., 2016; Notarnicola et al., 2016; Unger et al., 2016). Life cycle costing (LCC) has been applied to FW only in a limited number of studies and without consistent practices (De Menna et al. 2016). In general, the goal and scoping phase (e.g. problem assessed or system function) can be characterized by a large flexibility, thus leading to various effects in other methodological aspects. Results from FW related studies are therefore not comparable, causing potential misinterpretation by non-experts. Even experienced LCA and LCC practitioners could find difficulties in making specific methodological choices related to FW or an integrated approach for LCA and LCC, as both the ILCD handbook (EC, 2010) and the guidance on product environmental footprints – PEF (EC, 2013) focus on the driving product of a system, rather than waste flows.

The EU H2020 funded project REFRESH (Resource Efficient Food and dRink for the Entire Supply cHain) aims to contribute to food waste reduction throughout the food supply chain, and evaluate the environmental impacts and life cycle costs. Within the REFRESH project , the objective of this study was thus to develop a consistent approach in combining LCA and LCC, specifically to assess impacts of prevention of resource inefficiencies, new/novel valorisation options and waste handling options relating to side-flows in the food supply chain.

2. Methodology

In a first step of the REFRESH project, literature on LCA and LCC of food waste was systematically reviewed to identify relevant methodological aspects. Sources included existing LCA and LCC standards documentation, academic journal papers, policy guidelines, and case studies on FW. The specific aim of the review was to identify possible approaches, main differences among studies, standards and protocols, main challenges and knowledge gaps. Detailed results and list of sources of this review are presented in two REFRESH reports (respectively Unger et al., 2016 and De Menna et al., 2016).

As far as LCA of food systems is concerned (Unger et al., 2016), several sources provide guidance on environmental assessment of food systems, but they leave

a lot of room for LCA scoping. For example, standards and generic guidelines cover many products and services, but they do not provide step-by-step instructions on how to perform an LCA. Thus food waste stakeholders, who may have a deep understanding of their system but only a generic knowledge of LCA, would not find straightforward answers to specific modelling questions. Common issues include:

- Selection of attributional or consequential types of study;
- Establishing appropriate and coherent functional unit and system boundaries connected to the question(s) being addressed;
- Addressing multi-functionality (allocation vs. system expansion) and product substitution issues;
- Selection of impact indicators and interpretation of results.

As far as LCC is concerned, the review identified a widespread array of existing definitions and approaches (De Menna et al., 2016). Additionally, only a limited number of case studies were retrieved. These are mostly concerned with municipal FW management, and only a few included prevention issues. The following challenges could be identified:

- Lack of detailed recommendations for combining LCC and LCA;
- Use of LCC in case of consequential LCA studies;
- Differences between cut-off levels / scoping boundaries;
- Relevant cost categories for FW;
- Inclusion of economic impact indicators other than cost;

Based on the identified challenges, a specific framework was developed with the aim of providing a step-by-step assessment guidance for food waste practitioners (Davis et al., 2017). The framework is composed of a introductory section on study purpose definition, three decision trees - respectively on assessment situation(s), costing approach, and type of study (footprint vs. intervention) - and two sets of recommendations.

The framework was first submitted to and reviewed by selected LCA, LCC, and FW experts and practitioners within the REFRESH consortium. Then, it will be tested with selected case studies in a later task of the project.

3. Results and discussion

The overall structure of the framework is provided in Fig. 1. First, the assessor needs to identify the purpose of the study. As highlighted by existing standards and literature, the question addressed in the goal and scope phase can result in very different outcomes in terms of methodological choices. In the current framework, the main elements to includein the description of the purpose of the study are:

- Indication of the product/process under analysis (what product, waste flow, and characteristics?);
- Decisions on:
 - whether the goal is to assess a current situation or changes to an alternative scenario,
 - whether prevention is included or foreseen, and
 - whether some value is or will be involved in management of the side flow.

Once the purpose of the study is established, the next step is to identify whether the flow under study should be considered a driving product or a side flow (Davis et al, 2017). A flow of the food supply chain can be characterized as a driving product whenever it represents the main reason for the supply chain to exist. This means that in some agro-food processes there can be several driving products, all of which are justifying a certain share of the studied system.

On the contrary, any wasted edible and inedible part of food - including wasted flows of driving product(s) - can be defined as side flow. The main difference with the driving product is that an assessor would like to minimize it, rather than producing more of it. In the REFRESH framework, since the focus is on impacts of food waste, guidance and recommendations are provided with reference to the assessments of such side flows. Instead, no guidance is given on the evaluation of driving products.

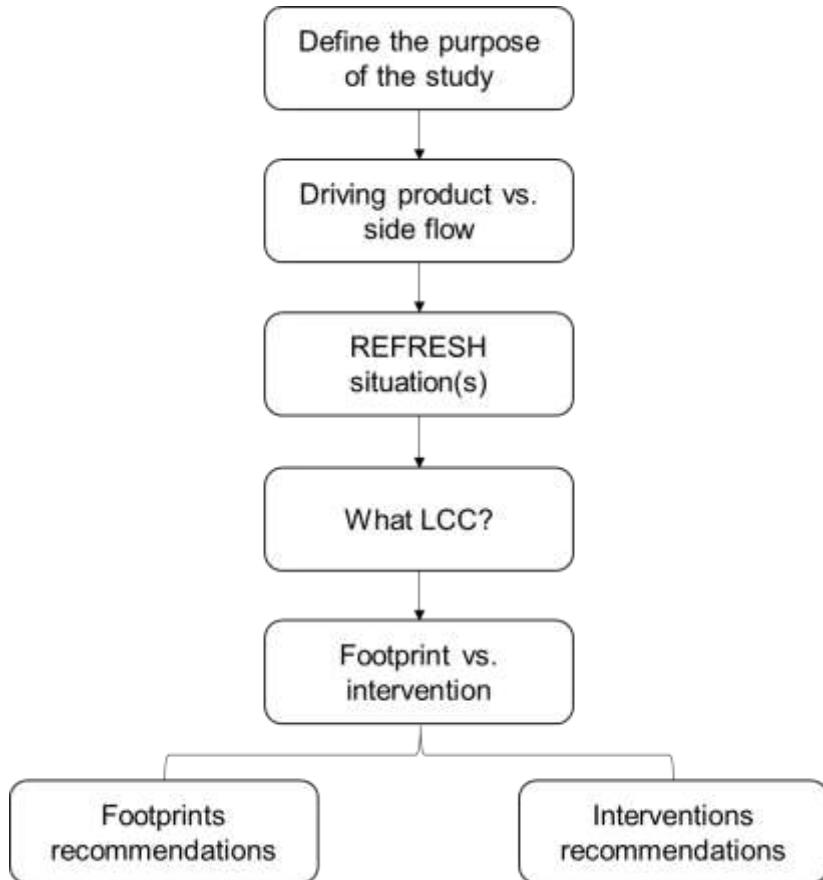


Figure 1: Framework structure.

Once the purpose and subject of the study are defined, it is important to identify the potential situation(s) to assess. A practitioner could for example want to evaluate impacts of a specific prevention measure or estimate potential costs and impacts of a prospective pilot plant. While side flows and life cycle stages may be different, any given assessment situation will share certain methodological commonalities.

To categorise systems suitable for the assessment, the concept of “REFRESH situations” (RS) has been developed (Unger *et al.*; 2016, De Menna *et al.*, 2016; and Davis *et al.*, 2017). The REFRESH situations (RS) include: Prevention of side flow (RS 1), side flow valorisation (RS 2), valorisation as part of waste management (RS 3), and end-of-life treatment (RS 4). REFRESH situations can take place at any point/process within the life cycle, within the remit of any stakeholder (including consumers) and are independent of the perspective taken, i.e. of the producer of side stream or the receiver. For each REFRESH situation, specific recommendations on setting of system boundary, functional unit(s) and handling of multi-functionality in relation to the stated problem are provided (beside other aspects). This categorization was then translated into a decision tree meant to help practitioners in the selection of relevant situations.

Since several LCC approaches exists (Hunkeler et al. 2008), another decision tree was developed for the selection of the most appropriate choice. Specifically, the integrated framework foresees the combined use of LCA and LCC. Therefore, the assessor, depending on the initial purpose and the deriving typology of costs that he might include, can choose between Conventional, Societal, and Environmental LCC. Since Conventional LCC does not have consistent boundaries with LCA while research is still needed on several aspects of Societal LCC, the Environmental LCC is the recommended approach.

Subsequently to RS and LCC approach choice, the last decision tree is related to the modelling approach to be used. In fact, depending on the question asked by the assessor, the appropriate modelling could differ. In particular, the framework builds on the distinction between attributional and consequential approaches and coherently identifies two type of studies: footprint studies and intervention studies.

Studies that are evaluating the impact deriving from a product (e.g. providing a snapshot of a valorized product from a side flow) and are not focusing on the consequences on other parts of the economy can be defined as footprint studies of side flows. Therefore, the modelling approach in this case is the attributional one. In such case, the study is usually referring all impacts on the valorized product from the side flow. Footprint studies can be carried out only for RS2, 3, and 4.

On the contrary, if the aim of the assessor is to estimate the effects of certain changes in a system (e.g. changing from waste management to the prevention of a side flow), then an intervention study should be carried out. In this case, the end/future situation (including RS1) is compared to the current situation and impacts of all changes are evaluated. Therefore, the modelling approach is consequential and the functional unit is constituted by the prevented/valorized/managed side flow.

Finally, the framework provides two sets of recommendations on selected issues for LCA and LCC, respectively for footprint and intervention studies. In the specific, indications are provided for:

- Functional unit
- System boundaries
- Multifunctionality
- Cut-off principles
- LCA inventory and cost modelling
- Impact assessment (separate and combined)
- Interpretation of results.

4. Conclusions

This study aimed to develop a consistent approach, combining LCA and LCC specifically to assess impacts of prevention of resource inefficiencies, new/novel valorisation options, and waste handling options related to side flows of the food supply chain.

Several challenges and methodological issues were identified through a literature review of LCA and LCC of FW. A specific framework was then developed to provide a step-by-step assessment guidance for food waste practitioners. Recommendations are provided on the study purpose definition, specific typologies of assessment situation(s), costing approach and methods, combined LCA and LCC modelling.

Recommendations are applicable to all levels of the waste hierarchy stating a generic order of preference for handling of side flows. The food waste hierarchy provides guidance on the identification and selection of the most preferred interventions.

This approach can support informed decision-making and in the long term promote the design of sustainable and cost-efficient interventions and more resource efficient food supply chains. Finally, food loss and waste reduction present also relevant social (e.g. availability of food) and political implications that should be considered together with the results obtained from any LCA and E-LCC.

5. Acknowledgements

This work was supported by the REFRESH (Resource Efficient Food and dRink for Entire Supply cHain) project, funded by the European Union Horizon 2020 Research and Innovation Programme under Grant Agreement No. 641933. More details on the REFRESH project can be found at <http://eu-refresh.org>.

6. References

Corrado, S, Ardente, F, Sala, S, Saouter, E, 2017. Modelling of food loss within life cycle assessment: From current practice towards a systematisation. *J. Clean. Prod.* 140, 847–859. doi:10.1016/j.jclepro.2016.06.050

Davis J, De Menna, F, Unger, N, Östergren, K, Loubiere, M and Vittuari, M, 2017. Generic strategy LCA and LCC - Guidance for LCA and LCC focused on prevention, valorisation and treatment of side flows from the food supply chain. SP Rapport 2017:01, ISBN 978-91-88349-84-2. Accessible at: <http://eu-refresh.org/generic-strategy-lca-and-lcc>

De Menna, F, Loubiere, M, Dietershagen, J, Vittuari, M, Unger, N 2016. Methodology for evaluating LCC. REFRESH Deliverable 5.2, ISBN: 978 - 94 - 6257 - 722 – 0

European Commission (EC), 2008. Directive 2009/98/EC of the European Parliament and of the Council of 19 November 2008 on Waste Repealing Certain Directives, Official Journal of the European Union, European Commission, 2008/98/EC 22.11.2008

European Commission (EC) Joint Research Centre – Institute for Environment and sustainability, 2010. International Reference Life Cycle Data System (ILCD) Handbook – General guide for Life

Cycle Assessment – Detailed guidance. First edition March 2010. EUR 24708 EN. Publications Office of the European Union, Luxembourg, LU.

European Commission (EC), 2013. Commission Recommendation of 9 April 2013 on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations. ANNEX II: Product Environmental Footprint (PEF) Guide. Official Journal of European Union, European Commission, 2013/179/EU

European Commission, 2015. An EU action plan for the circular economy

FAO, 2011. Global Food Losses and Food Waste: Extent, Causes and Prevention. Rome, Italy: UN FAO. Accessible at: <http://www.fao.org/docrep/014/mb060e/mb060e.pdf>

FAO, 2013. Food Wastage Footprint: Impacts on Natural Resources. Rome, Italy: UN FAO. Accessible at: <http://www.fao.org/docrep/018/i3347e/i3347e.pdf>

FAO, 2014. Food Wastage Footprint: Full cost-accounting, Food and Agriculture Organization of the United Nations (FAO). ISBN 978-92-5-107752-8

FUSIONS, 2014. FUSIONS Definitional Framework for Food Waste Accessible at: <http://eufusions.org/phocadownload/Publications>

Gruber, LM, Brandstetter, CP, Bos, U, Lindner, JP, Albrecht, S, 2016. LCA study of unconsumed food and the influence of consumer behavior. *Int. J. Life Cycle Assess.* 21, 773–784. doi:10.1007/s11367-015-0933-4

Hunkeler, D, Lichtenvort, K, Rebitzer, G ed. 2008. Environmental Life Cycle Costing. Pensacola, CRC Press, ISBN 9781420054705

International Organization for Standardization (ISO) 2006. "Environmental management—Life cycle assessment: Requirements and Guidelines". ISO14044, Geneva

Kummu, M, de Moel, H, Porkka, M, Siebert, S, Varis, O, and Ward, PJ, 2012. "Lost Food, Wasted Resources: Global Food Supply Chain Losses and Their Impacts on Freshwater, Cropland, and Fertiliser Use." *Science of the Total Environment* 438: 477–489

Notarnicola, B, Tassielli, G, Renzulli, PA, Castellani, V, Serenella, S, 2016. Environmental impacts of food consumption in Europe. *J. Clean. Prod.* doi:10.1016/j.jclepro.2016.06.080

Östergren, K, 2016. From harmonised measurement to strategic action, FUSIONS framework, dataset and recommendations, presentation, May 19, EPM, 2016, accessible at <http://www.eufusions.org>

Unger N, Davis J, Loubiere, M, Östergren, K, 2016. Methodology for evaluating environmental sustainability. REFRESH Deliverable 5.1

Vittuari, M, De Menna, F, Pagani, M, 2016. The Hidden Burden of Food Waste: The Double Energy Waste in Italy. *Energies* 9, 660. doi:10.3390/en9080660

ENEA – Servizio Promozione e Comunicazione

www.enea.it

Settembre 2017

Il Convegno è organizzato con in patrocinio di:



Setac Italian Branch



Società Chimica Italiana, Divisione di Chimica dell'Ambiente e dei Beni Culturali



Ordine dei Chimici
della Toscana



Ordine Ingegneri della Provincia di Siena



Ministero dell'Ambiente e della Tutela del Territorio e del Mare



Provincia di Siena



Comune di Siena

Sponsor del Convegno:



Centrofarc



Mater - Bi



CENTRO DI INFORMAZIONE

Europe Direct Siena



Tecno Service



La Bottega di Stigliano



Servizi Ecologici Integrati



ISBN 978-88-8286-352-4