Life Cycle Assessment
per la sostenibilità ambientale di prodotti, servizi, sistemi

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- Life Cycle Assessment: cos'è e perché
- Life Cycle Assessment: come e quando
- Life Cycle Assessment: opportunità e limiti
  - Riferimenti metodologici
  - Esempi e casi studio

CONSIGLIO NAZIONALE DEGLI INGEGNERI

CONVEGNI IN MODALITÀ ON LINE
MODULO 1 - Lunedì 25 maggio 2026, ore 15.00 - 18.00

Ingegneria e sostenibilità ambientale dei processi produttivi e dei prodotti

MODULO 1:
Lunedì 25 maggio 2026, ore 15.00 - 18.00
Life Cycle Assessment per la sostenibilità ambientale di prodotti, servizi, sistemi

OBIETTIVI
Apprendere, mediante spiegazioni teoriche e analisi di casi studio, in cosa consiste la valutazione di ciclo di vita (Life Cycle Assessment) e come può essere utile a migliorare le prestazioni ambientali di prodotti, servizi, sistemi, nei diversi ambiti settori economici e produttivi.

ARGOMENTI:
- Introduzione alla metodologia Life Cycle Assessment (LCA)
- Fasi e contenuti di uno studio LCA
- Come utilizzare i risultati di LCA per innovare

MODULO 2:
Venerdì 29 maggio 2026, ore 15.00 - 18.00
Ecolabelling per dimostrare la sostenibilità ambientale di prodotti, servizi, sistemi

OBIETTIVI
Apprendere, mediante spiegazioni teoriche e analisi di casi studio, in cosa consiste l'etichettatura ambientale di prodotto (Ecolabelling) e come può essere utilizzata a supporto del green marketing a livello nazionale, europeo e internazionale.

ARGOMENTI:
- Introduzione all'ecolabelling
- Criteri Ambientali Minimi (CAM)
- Environmental Product Declaration (EPD)
- Product Environmental Footprint (PEF)

Nice to meet you!

Sustainability Assessment and Management SAM.lab

https://research.dii.unipd.it/sam/

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Teacher of Life Cycle Assessment
- Degree course in Environmental Engineering
- Master Degree course in Safety Engineering
- Master Degree course in Circular Economy

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https://www.unipd.it/sam-skills

Main research topics:
- Sustainability Assessment in industrial processes
- Life Cycle Sustainability Assessment in End-of-Life and Upcycling
- Life Cycle Management in circular innovation

https://scholar.google.com/citations?user=dgSls_4AAAAJ&hl=it

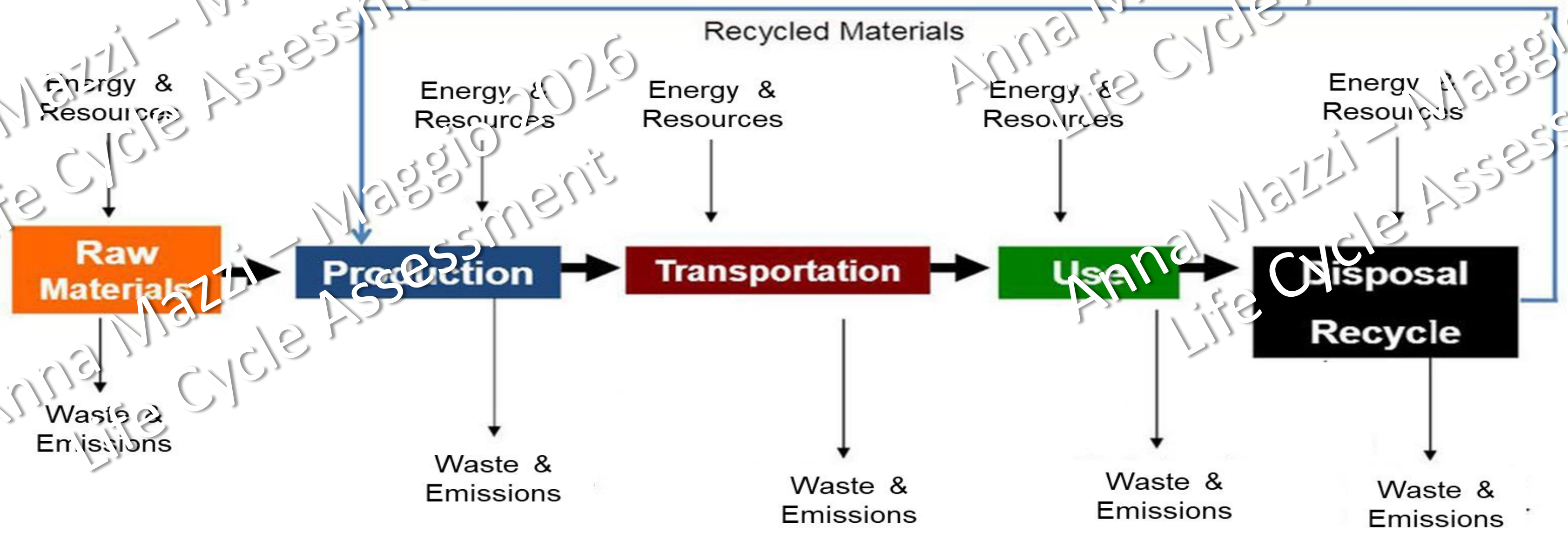
- Life Cycle Assessment: cos'è e perché
- Life Cycle Assessment: come e quando
- Life Cycle Assessment: opportunità e limiti
  - Riferimenti metodologici
  - Esempi e casi studio

Intro – approccio «Life Cycle»

Il prodotto viene analizzato e preso in considerazione in funzione dei **flussi di materia, energia ed emissioni** delle attività che lo accompagnano **durante tutto il suo ciclo di vita**

Tutta la vita del prodotto è intesa come un insieme di attività e di processi, ognuno dei quali:

- assorbe una certa quantità di materia ed energia
- opera una serie di trasformazioni
- rilascia emissioni di varia natura (rifiuti, emissioni in atmosfera, nel suolo, in acqua, ecc.)



Life Cycle Thinking e Life Cycle Assessment

PRODOTTO

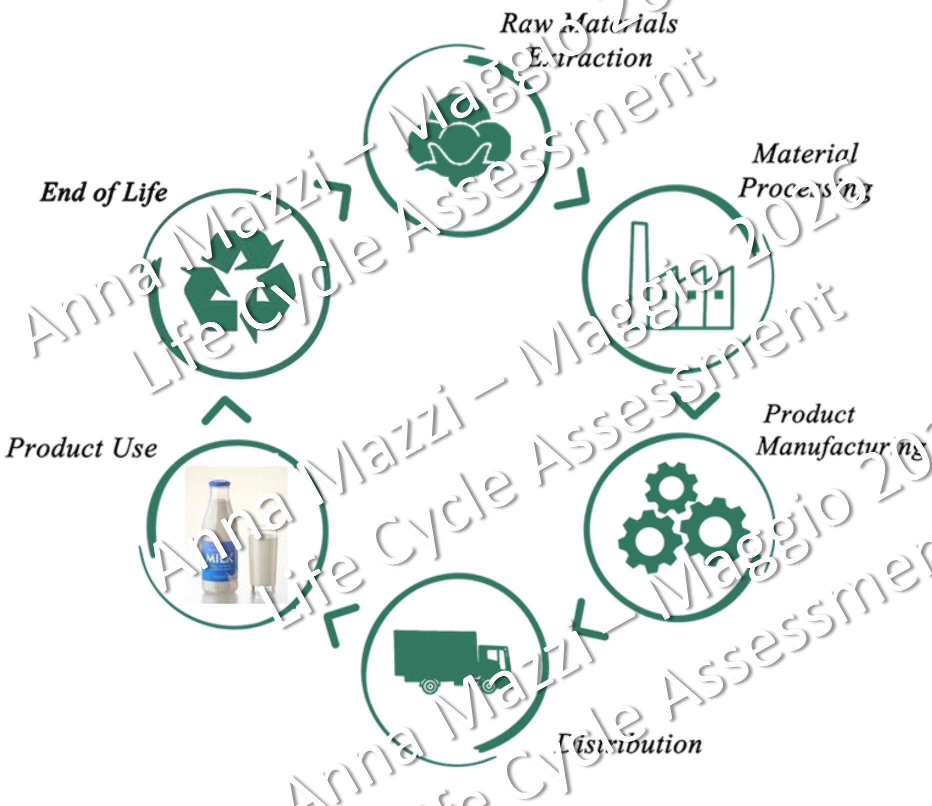
- PROGETTAZIONE
- PRODUZIONE
- TRASPORTO
- UTILIZZO
- DISMISSIONE
- RECUPERO e/o SMALTIMENTO

- **COSTI ECONOMICI:** catena del valore
- **IMPATTI AMBIENTALI:** diretti e indiretti
- **IMPATTI SOCIALI:** lavoratori, territorio, collettività

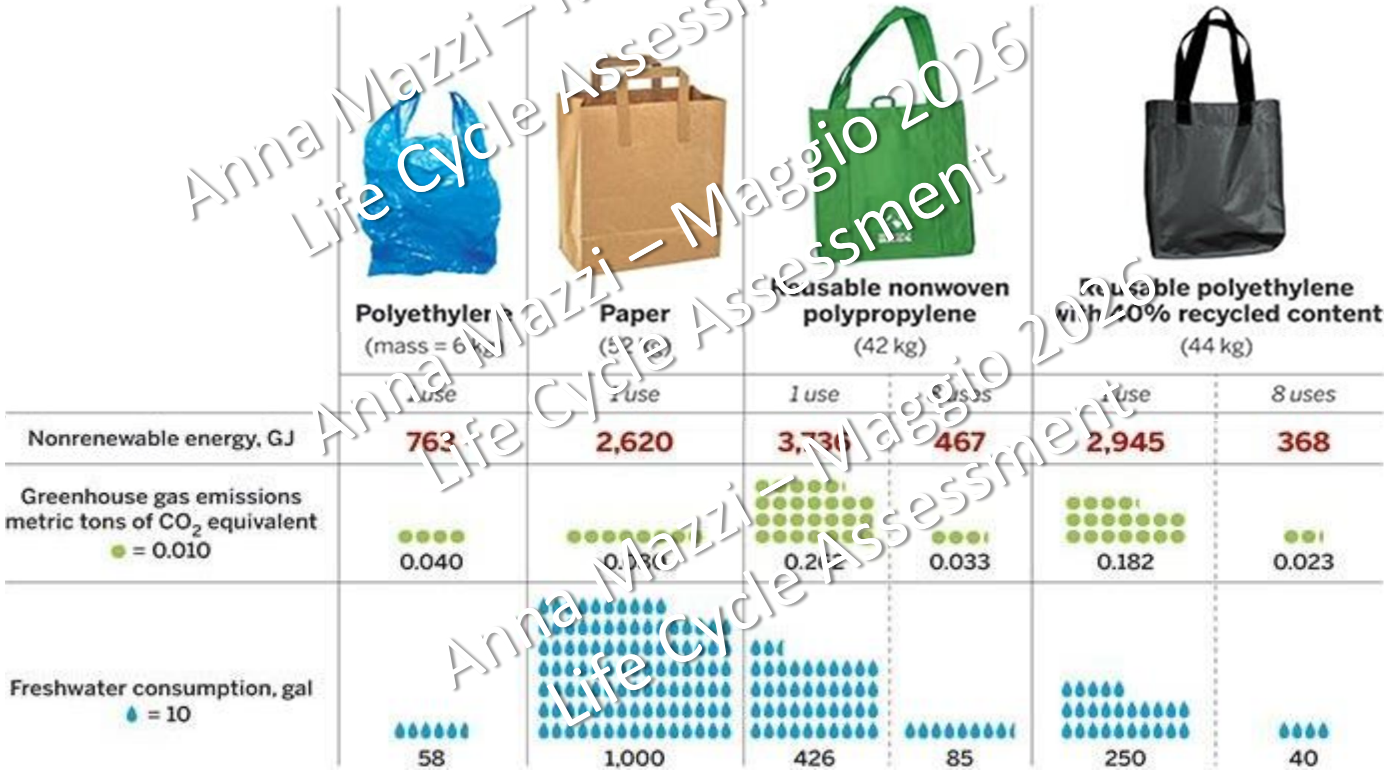
LIFE CYCLE ASSESSMENT = principale strumento operativo del Life Cycle Thinking

Identifica e quantifica gli **impatti ambientali** associati al LC di un prodotto/servizio

The case of milk bottle …



The case of sustainable bag …



➡ Life cycle assessment: to avoid risk of «burden shifting»

LCT e LCA nell'Agenda 2030

A successful transition will mean improvements in resource efficiency, consideration of the entire life cycle of economic activities, and active engagement in multilateral environmental agreements.

Governments need to implement and enforce policies and regulations that include measures such as setting targets for reducing waste generation, promoting circular economy practices, and supporting sustainable procurement policies.

It's in businesses' interest to find new solutions that enable sustainable consumption and production patterns. A better understanding of environmental and social impacts of products and services is needed, both of product life cycles and how these are affected by use within lifestyles.

Innovation and design solutions can both enable and inspire individuals to lead more sustainable lifestyles, reducing impacts and improving well-being.

Making informed purchases also helps. By buying from sustainable and local sources you can make a difference as well as exercising pressure on businesses to adopt sustainable practices.

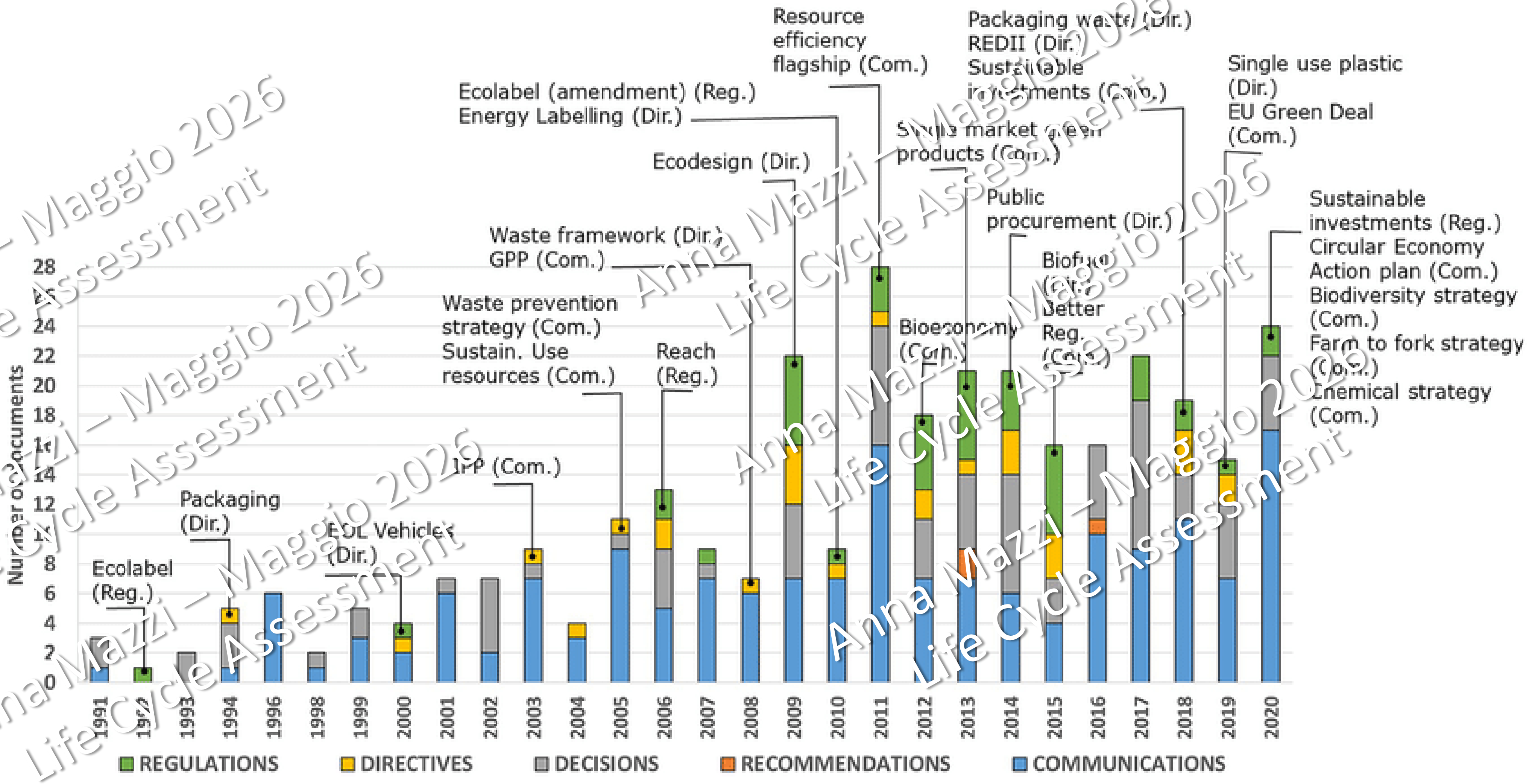
DECADE OF >>> ACTION

Ten years to transform our world

LCT e LCA nella politica europea

European Commission

EU Environmental policies integrating LCT and LCA in the last 20 years

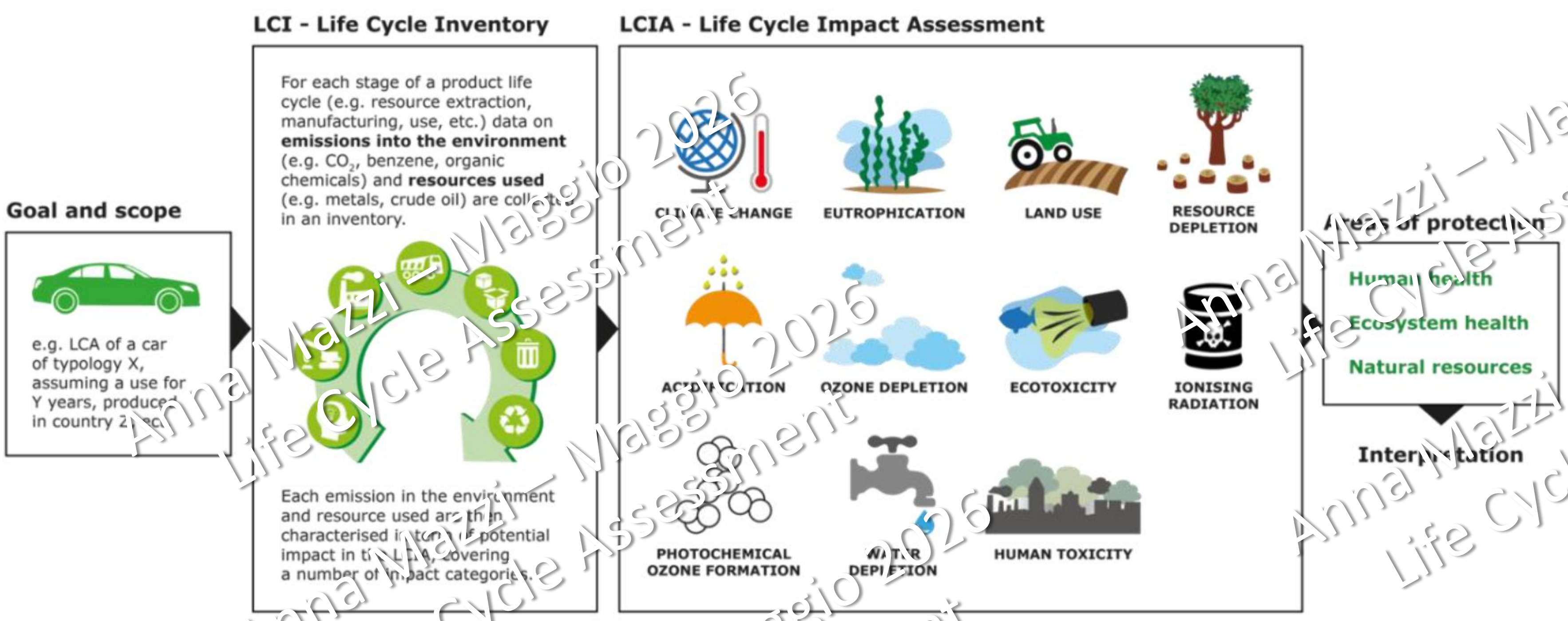


Sala et al, 2021. The evolution of life cycle assessment in European policies over three decades. https://doi.org/10.1007/s11367-021-01893-2

LCT e LCA nei piani strategici dell’UE

- Sustainable use of natural resources https://ec.europa.eu/environment/natres/index.htm
- European Waste Strategy https://ec.europa.eu/environment/waste/strategy.htm
- Environmental Technology Action Plan (ETAP) https://ec.europa.eu/environment/ecoap/about-action-plan/
- EU Directive in green public procurement (GPP) https://ec.europa.eu/environment/gpp
- European Green Deal https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en
- European Climate Action – 2050 long-term strategy https://ec.europa.eu/clima/eu-action/climate-strategies-targets/2050-long-term-strategy_en
- Farm2Fork Strategy for a fair, healthy and environmentally-friendly food system https://food.ec.europa.eu/horizontal-topics/farm-fork-strategy_en
- European Biodiversity Strategy for 2030 https://environment.ec.europa.eu/strategy/biodiversity-strategy-2030_en
- European Chemicals strategy for Sustainability towards a toxic-free environment https://environment.ec.europa.eu/strategy/chemicals-strategy_en
- European Strategy for Plastics in a Circular Economy https://eplca.jrc.ec.europa.eu/plasticLCA.html
- Single market for Green Products (Environmental Footprint labels PEF and EOF) https://ec.europa.eu/environment/eussd/smgp/dev_methods.htm
- Circular Economy Action Plan https://environment.ec.europa.eu/strategy/circular-economy_en
- Ecodesign for Sustainable Product Regulation (ESPR) https://eur-lex.europa.eu/eli/reg/2024/1781/oj/eng
- Green Claims Directive (proposal) https://environment.ec.europa.eu/publications/proposal-directive-green-claims_en

LCA nella politica europea



Life Cycle Assessment steps:
- goal and scope definition
- life cycle inventory
- life cycle impact assessment
- interpretation

Life Cycle Assessment goals:
- Identification and analysis of inputs-outputs flows
- Quantification of potential environmental impacts
- Environmental footprint assessment and comparison
- Green claims strategies
- Guidance in ecodesign and ecoinnovation

with “life cycle” approach

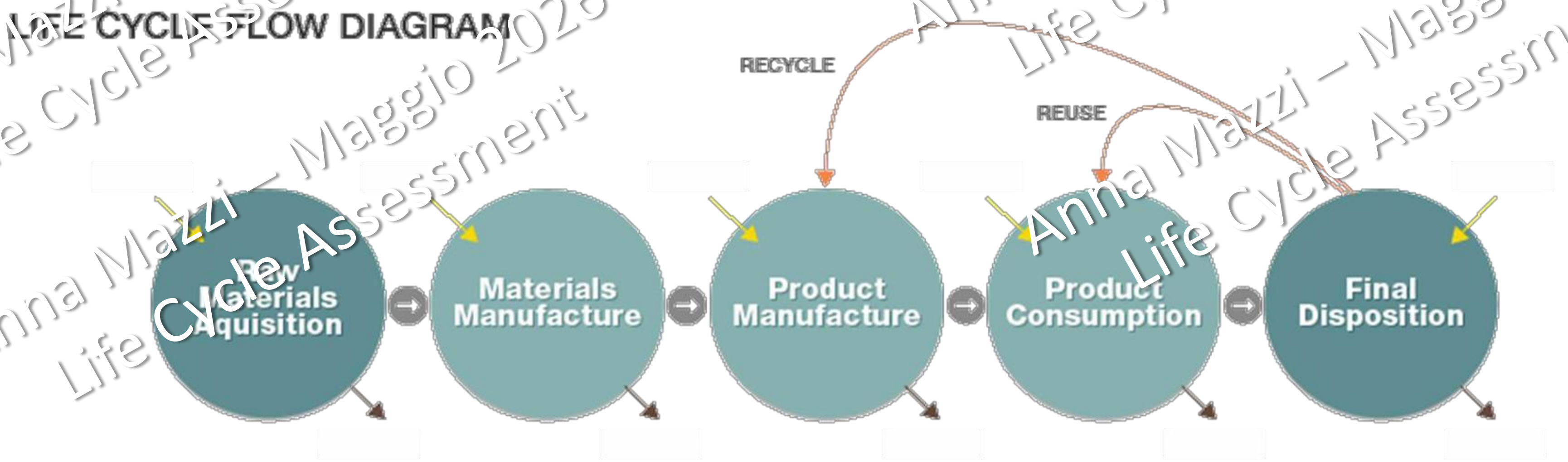
https://eplca.jrc.ec.europa.eu/lifecycleassessment.html

Life Cycle Assessment – di cosa si tratta

[ISO 14040 § 3.2]

Obiettivo: valutazione degli aspetti e dei potenziali impatti ambientali associati ad un prodotto nell'intero ciclo di vita

Contenuti: compilazione e valutazione attraverso tutto il ciclo di vita dei flussi in entrata e in uscita, nonché dei potenziali impatti ambientali di un sistema di prodotto



Life Cycle approach: le origini

- Progressivo spostamento dell'attenzione al PRODOTTO

Nuova definizione di PRODOTTO: insieme delle operazioni e degli input ed output materiali ed immateriali connessi con la realizzazione di una o più funzioni ben definite

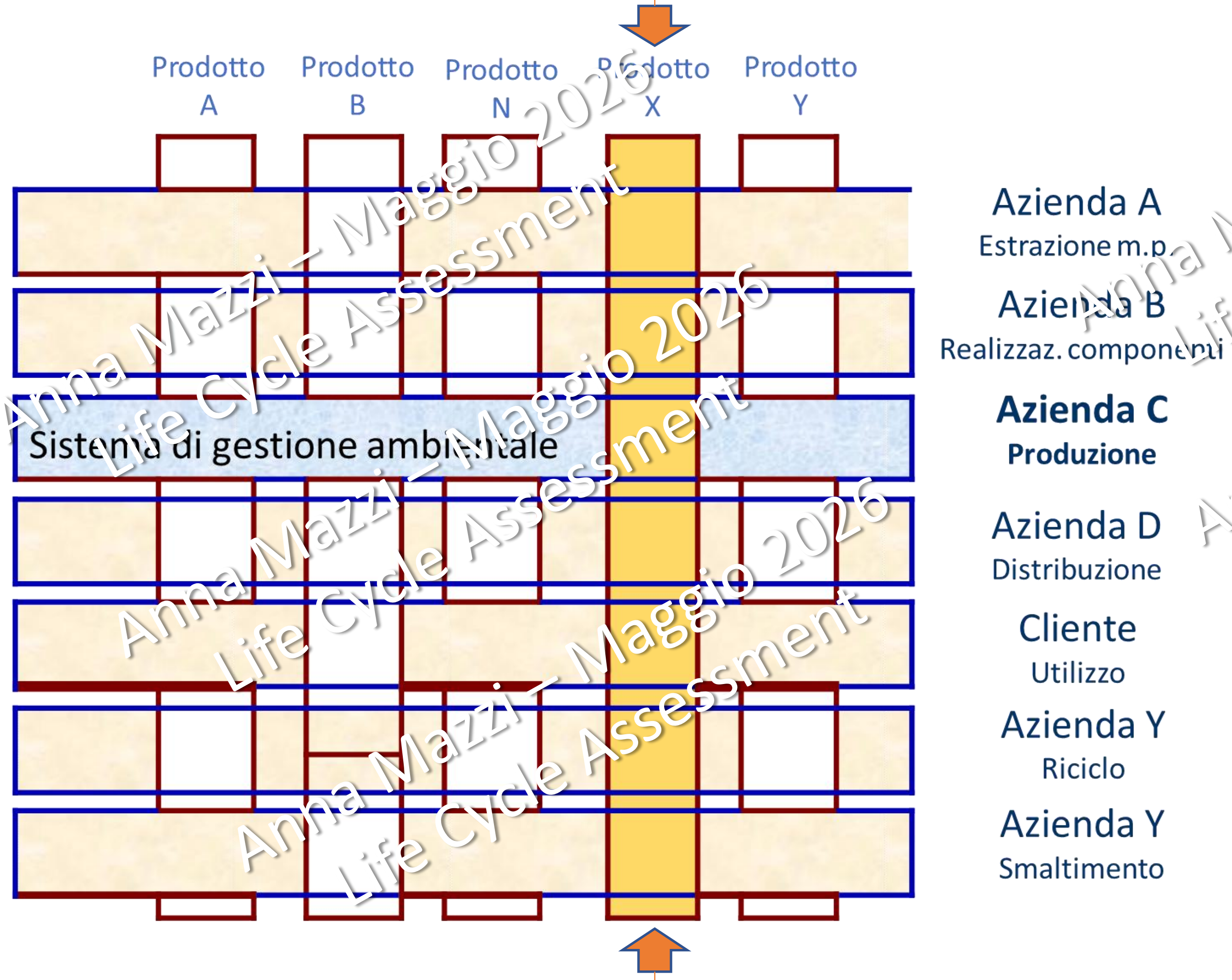
Necessità di uscire dalla visione strettamente circoscritta all'organizzazione verso un'analisi estesa a tutto il complesso sistema di elementi che contribuiscono alla realizzazione di un bene

- Progressivo interesse verso il COLLABORATIVE SUPPLY CHAIN

Collaborazione tra PRODUTTORI, FORNITORI E DISTRIBUTORI per un miglior servizio e una maggiore efficienza organizzativa

Necessità di collaborare con gli attori della filiera per individuare soluzioni gestionali più efficienti, a vantaggio di affidabilità del prodotto e soddisfazione del mercato

La prospettiva «life cycle»



Approccio orientato al PRODOTTO, che include tutte le fasi del suo ciclo vita, anche precedenti e successive a quella di riferimento

Possibili finalità di uno studio LCA

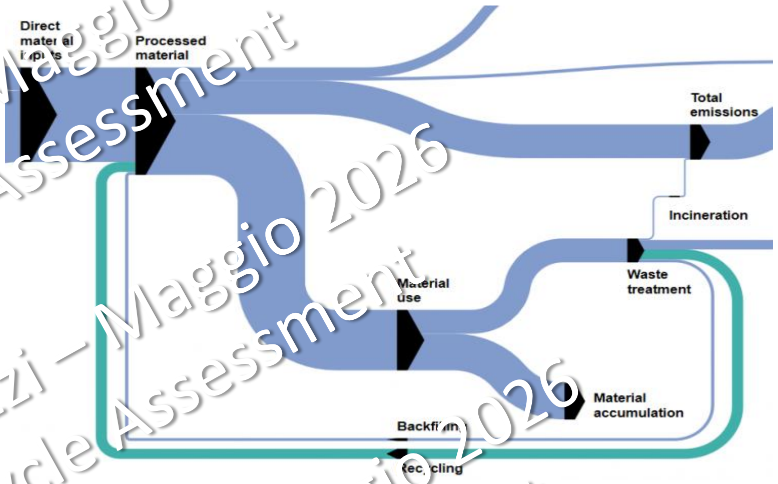
[ISO 14040]

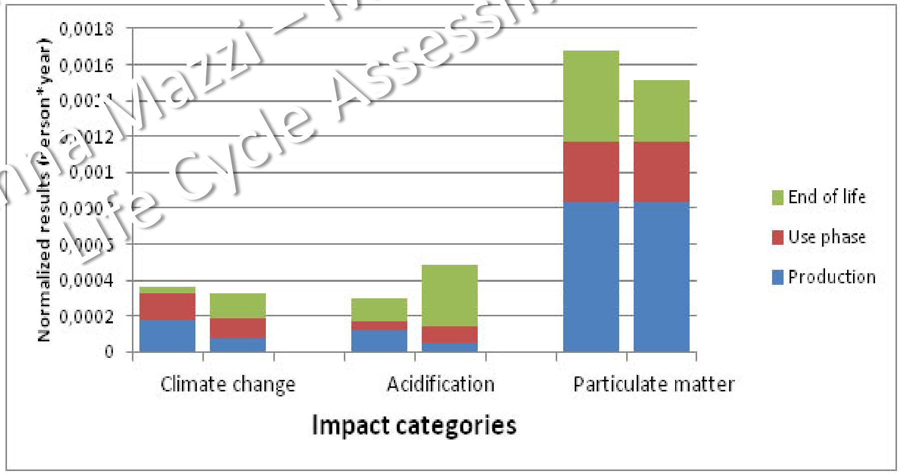
- Costruire un inventario di input e output di materia ed energia lungo tutte le fasi del ciclo di vita dei p/s e farne una valutazione qualitativa e quantitativa

- Ottenere il «profilo ambientale» del p/s quantificando gli impatti ambientali associati ad ogni attività del suo ciclo di vita

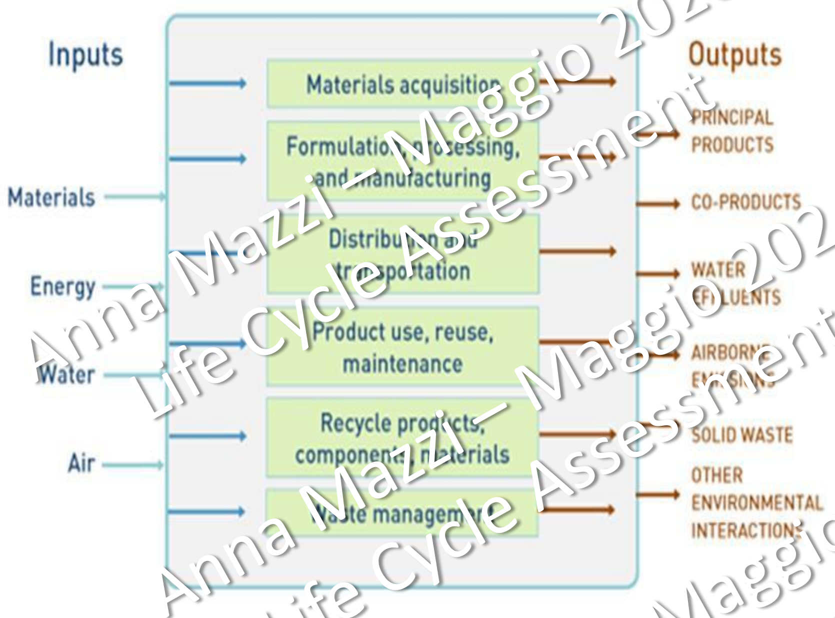
- Identificare gli aspetti ambientali più significativi del p/s per componenti, processi e fasi del ciclo di vita

- Valutare le opportunità di miglioramento ambientale da adottare per ridurre l'impatto complessivo del p/s



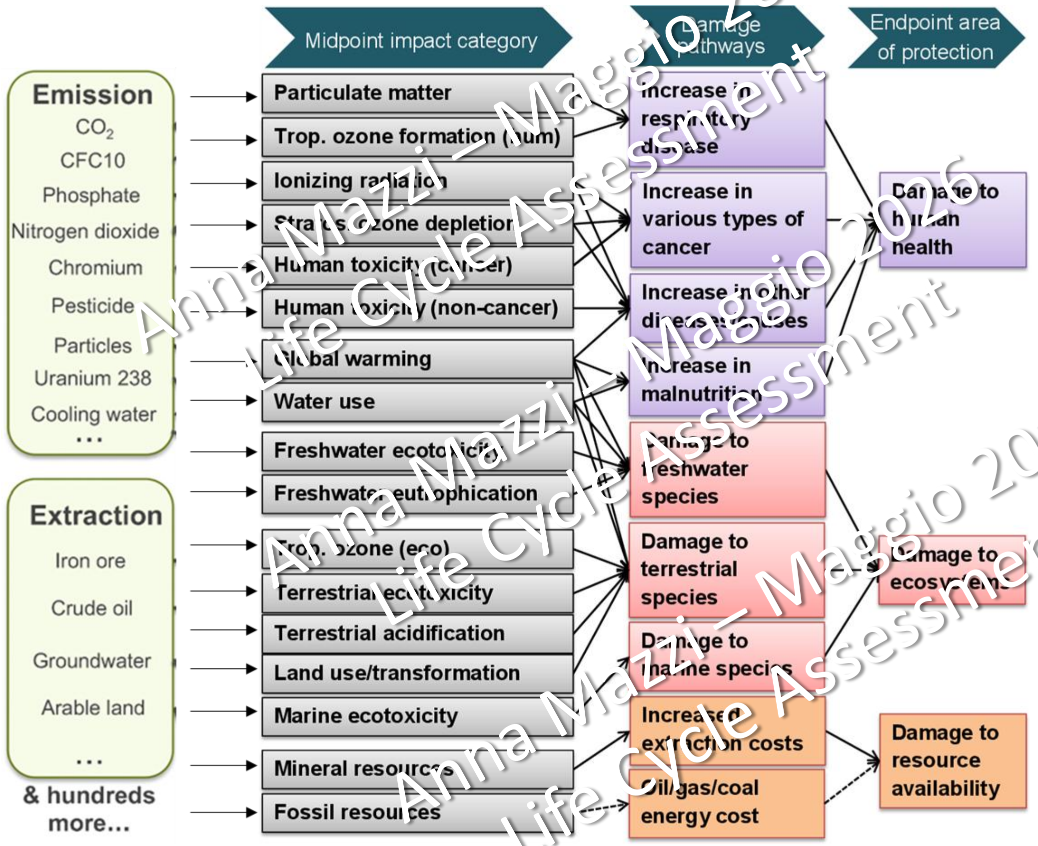


Contenuti di uno studio di LCA (highlights)



BILANCIO DI INPUT E OUTPUT DI MATERIA ED ENERGIA

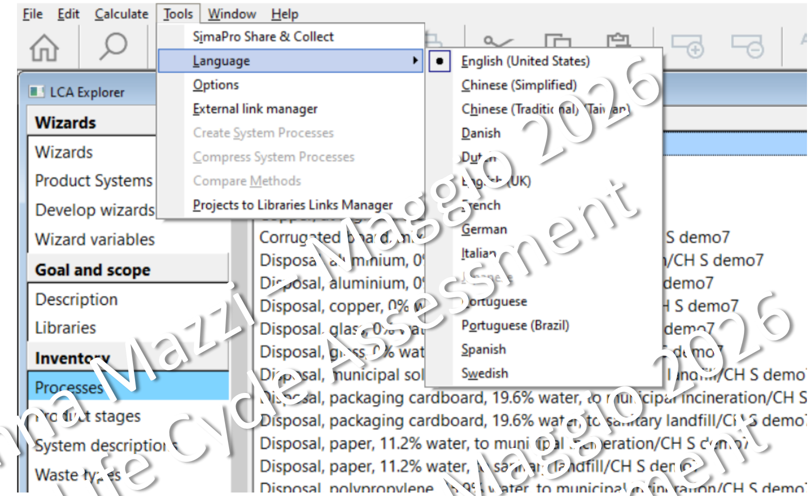
[Life Cycle Inventory]



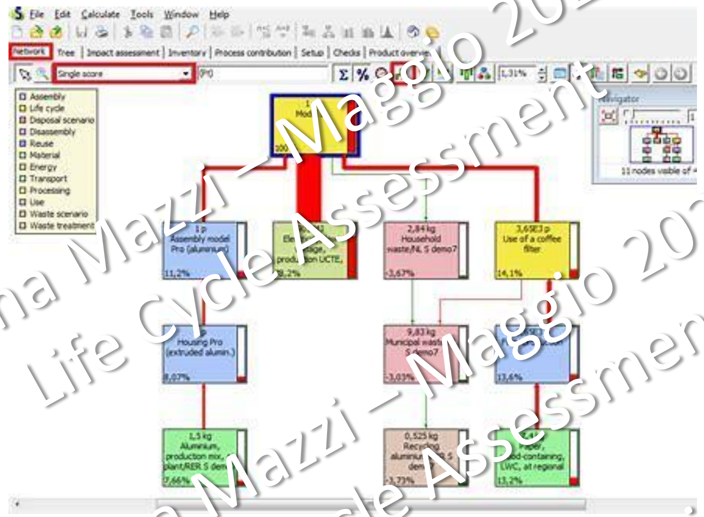
QUANTIFICAZIONE DEGLI IMPATTI AMBIENTALI PER OGNI CATEGORIA DI IMPATTO CON OPPORTUNI MODELLI DI CALCOLO

[Life Cycle Impact Assessment]

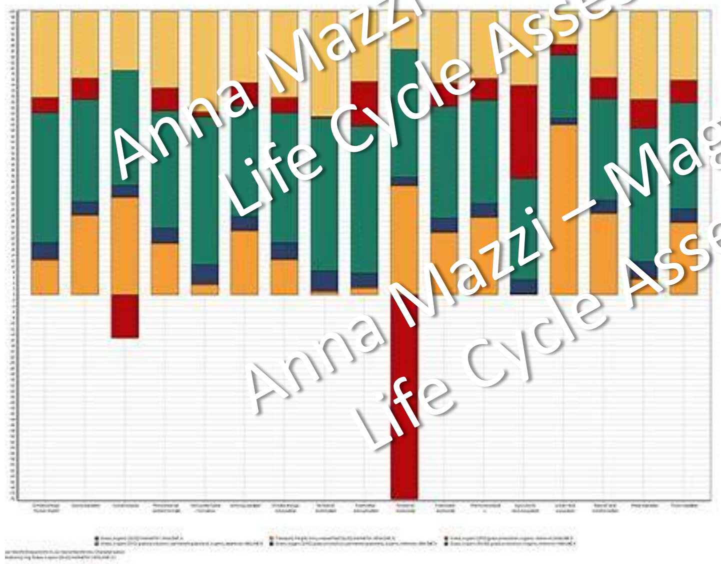
Software per LCA



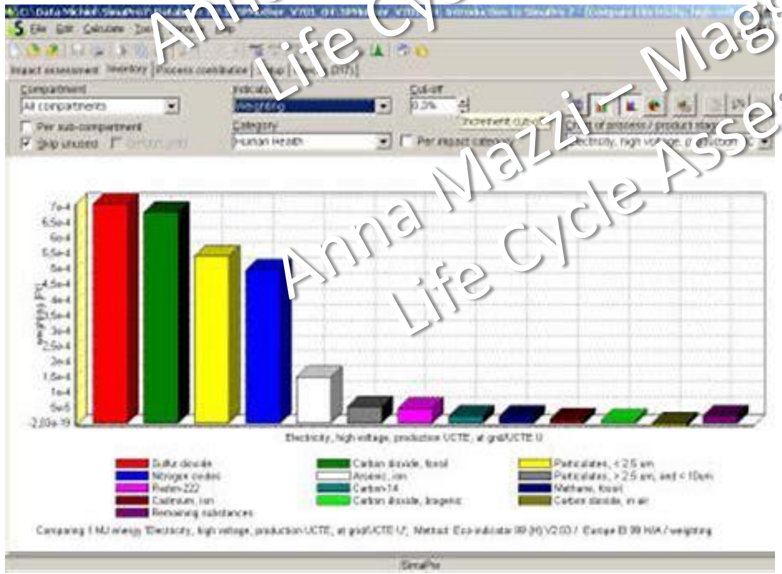
Goal & Scope



Inventory



Impact Assessment



Interpretation

Esempi di software per studi di LCA

- Ecochain - https://www.ecochain.com
- One Click LCA - https://www.oneclicklca.com
- OpenLCA - https://www.openlca.org
- SimaPro - https://www.simapro.com
- Sphera - https://www.sphera.com
- Umberto - https://www.ipoint-systems.com/software/umberto/
- TEAM (TM) - https://team-tools-for-environmental-analysis-an.software.informer.com/
- Idemat - https://idematapp.com/
- ESG metrics - https://esg-metrics.cikis.studio/
- … to be continued …

LCA per l'analisi degli aspetti significativi

Life Cycle Assessment of a Smartphone

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Abstract— It is of interest to understand the life cycle contribution from the use of smartphones including their network usage, as well as to gain knowledge regarding the impact of the smartphone as a device to provide input for network studies. This cradle-to- grave study is based on life cycle assessment (LCA) methodology as outlined by the ISO14040 series and the supplementing ICT specific LCA standard from ETSI/ITU. The paper provides details regarding data collection, assumptions, methods and results. Furthermore, sensitivity analysis results for selected parameters are presented, including variations due to different secondary data sets. This study calculates the Global Warming Potential (GWP) for the assessed smartphone (a Sony Mobile Z5, including accessories) to 57 kg CO_2e for an assumed operating life time of 3 years, excluding the network usage. Results are also presented for other impact categories and as yearly figures. In addition, the distribution of impacts between life cycle stages is provided for the assessed impact categories. Integrated circuit (IC) production is identified as a major contributor to the overall impacts followed by the production of the display. For GWP specifically, overall results are also provided including the network usage

Ercan and Kimfalk, 2017. Life Cycle Assessment of a Smartphone

A. The smartphone (Z3)	152 g (see details below)
B. Headset	16 g
C. USB-cable	21 g
D. Charger	50 g
E. Documentation	48 g
X. Delivery packaging	74 g (not included in picture)
Y. Transport packaging	66 g (not included in picture)

1.	Frame/backside	27 g (mainly plastics)
2.	Metal sheets	15 g
3.	Display	21 g (facing down, not visible)
4.	Battery	48 g
5.	PBAs/ICs	13 g
6.	Flex-films	6.5 g
7.	Cameras	1.5 g
8.	Other components	11 g

LCA per l'analisi degli aspetti significativi

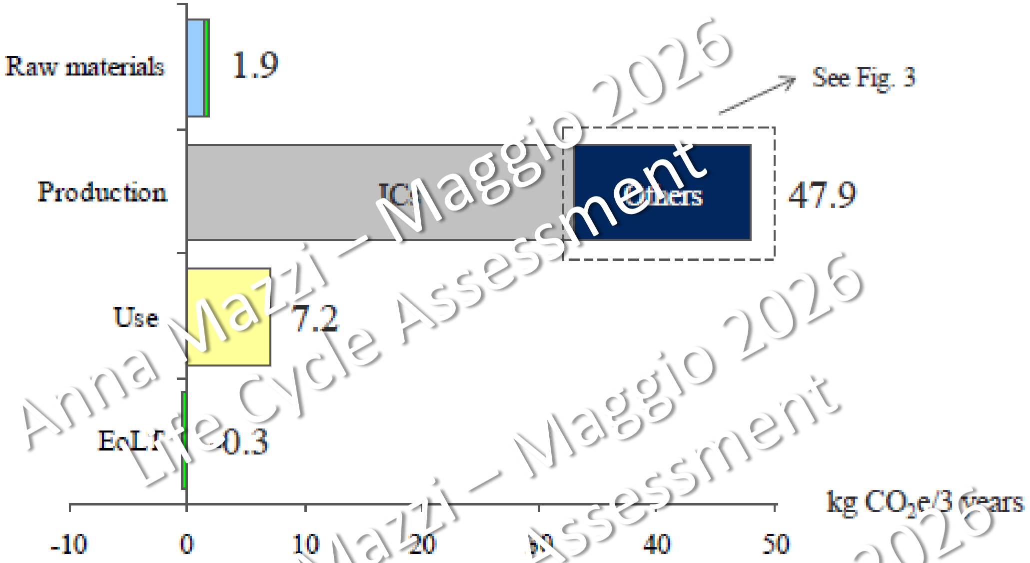
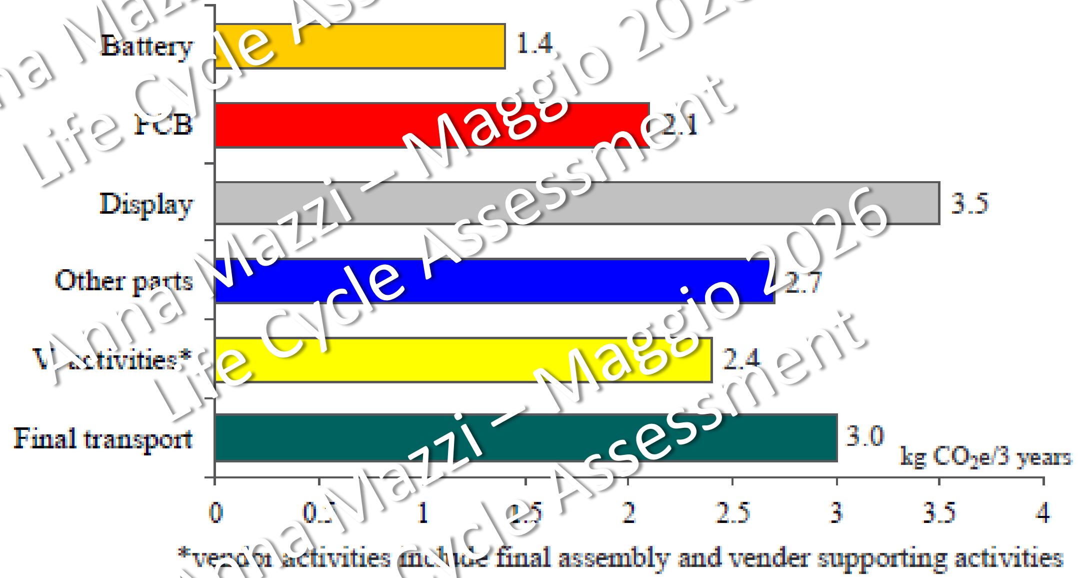


Fig.2 GWP for smartphone Z5 during its life time (3 years), including accessories but excluding network usage



*vendor activities include final assembly and vender supporting activities

Fig. 3 Total GWP results for all production processes but IC for Z5

Ercan and Kimfalk, 2017. Life Cycle Assessment of a Smartphone

LCA per l'analisi degli aspetti significativi

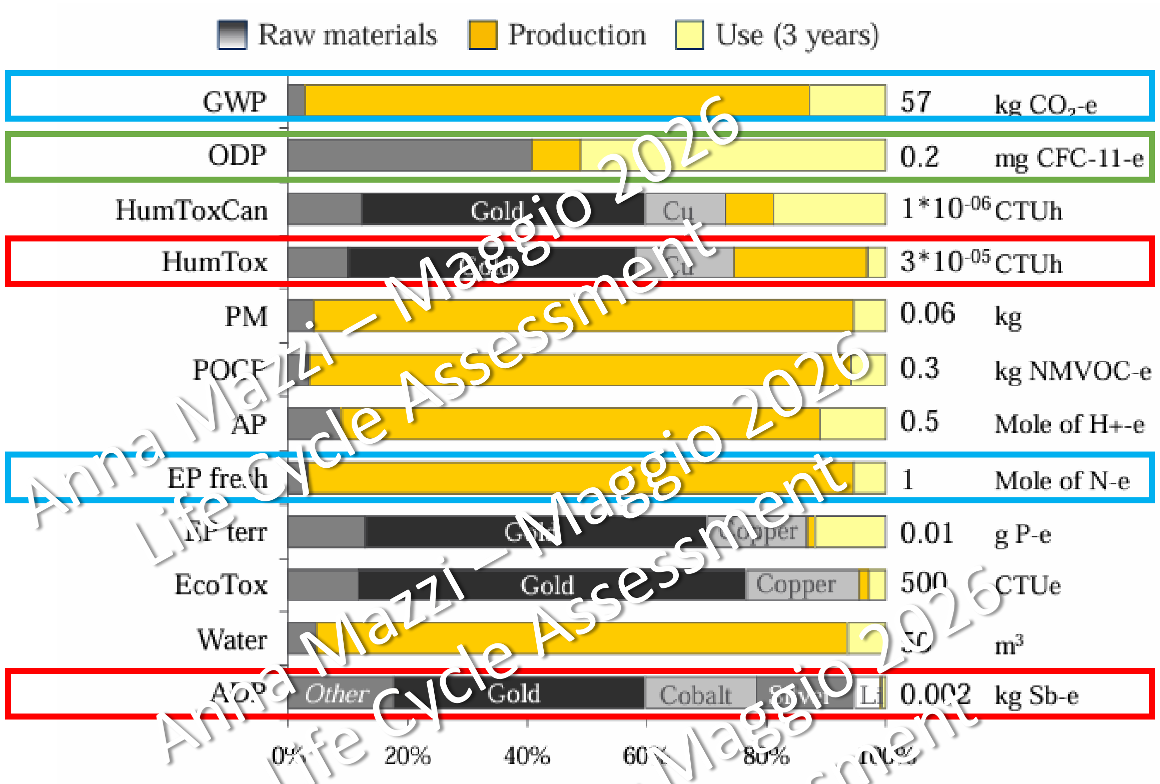
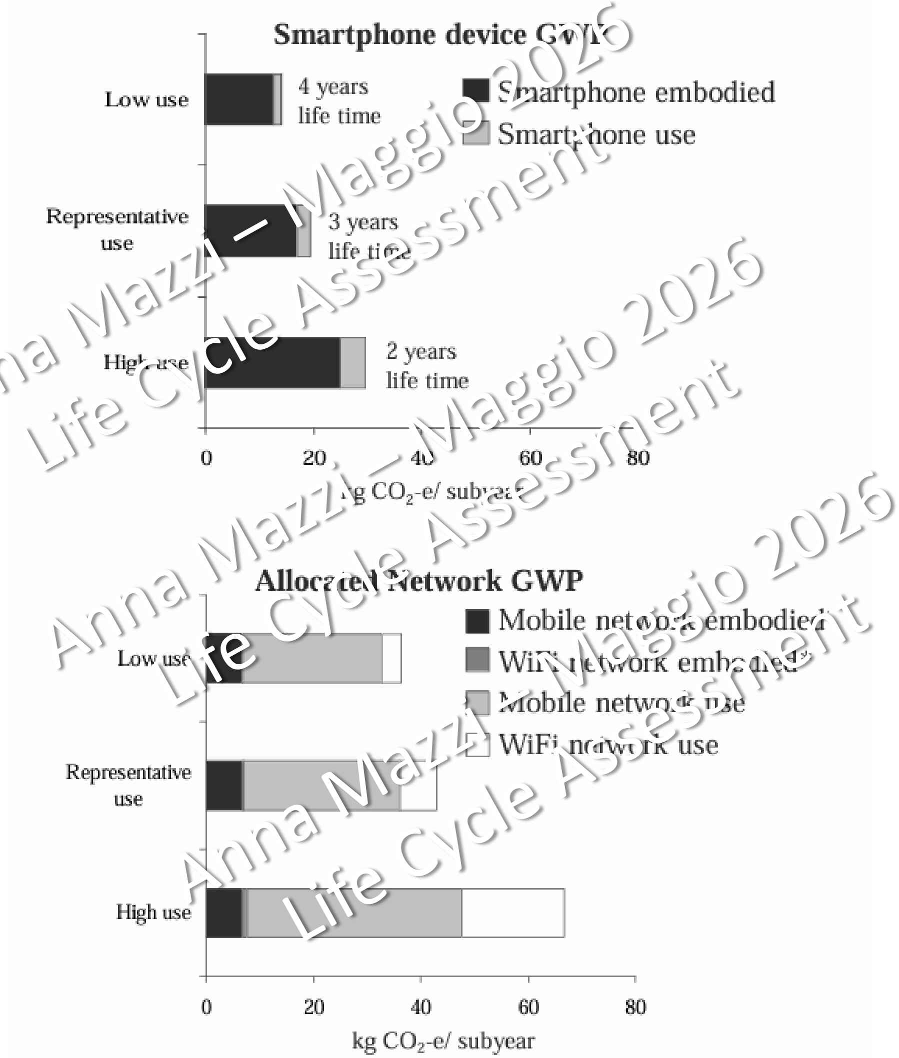


Fig. 4 Total life cycle result for all impact categories for smartphone Z5 with accessories using Ecoinvent database and adopting a 50/50 recycling approach with 19% recycling of gold assumed.

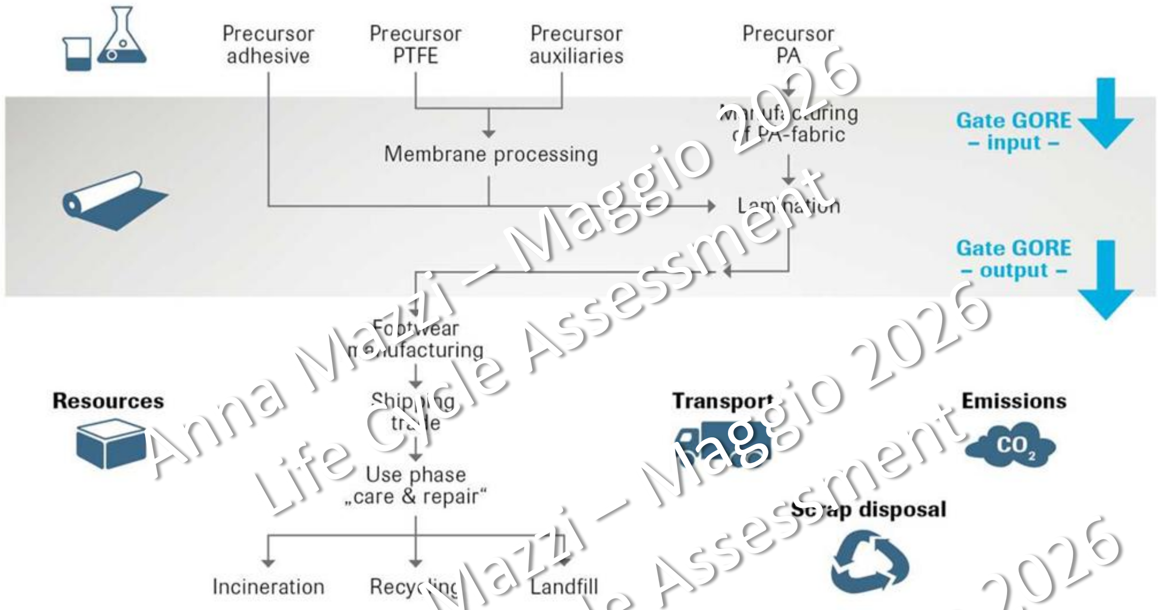
Ercan and Kimfalk, 2017. Life Cycle Assessment of a Smartphone

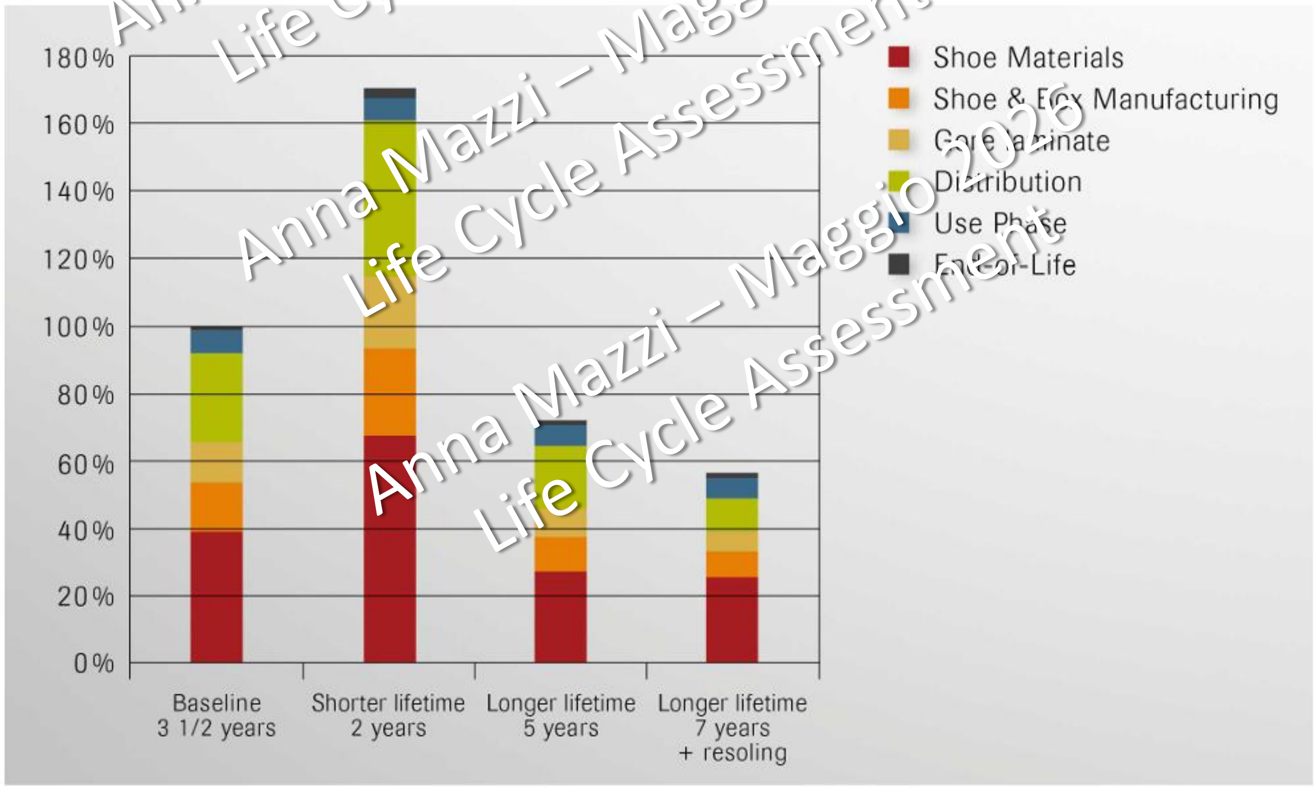


* Operator activities are included in network production

Figure 6 Sensitivity analysis of life time and data traffic

LCA per migliorare la sostenibilità dei prodotti





https://www.gore-tex.com/sites/default/files/assets/LCA%20Gore%20hiking%20boots%20summary%20report%20-%20Oct14.pdf

LCA per identificare gli hotspot ambientali

Environmental Impact Assessment Review 63 (2017) 12–22

Contents lists available at ScienceDirect

Environmental Impact Assessment Review

journal homepage: www.elsevier.com/locate/eiar

ELSEVIER

Life Cycle Assessment to support the quantification of the environmental impacts of an event

A B S T R A C T

In recent years, several tools have been used to define and quantify the environmental impacts associated with an event; however, a lack of uniform approaches for conducting environmental evaluations has been revealed. The aim of this paper is to evaluate whether the Life Cycle Assessment methodology, which is rarely applied to an event, can be an appropriate tool for calculating the environmental impacts associated with the assembly, disassembly, and use phase of an event analysing in particular the components and the displays used to establish the exhibits. The aim is also to include the issues reported by ISO 20121:2012 involving the interested parties that can be monitored but also affected by the event owner, namely the event organiser, the workforce and the supply chain.

A small event held in Northern Italy was selected as the subject of the research. The results obtained show that ... aluminium materials, ... analysis for estimat- ... uncertainty analysis has ... the energy consumed ... ation and assembly

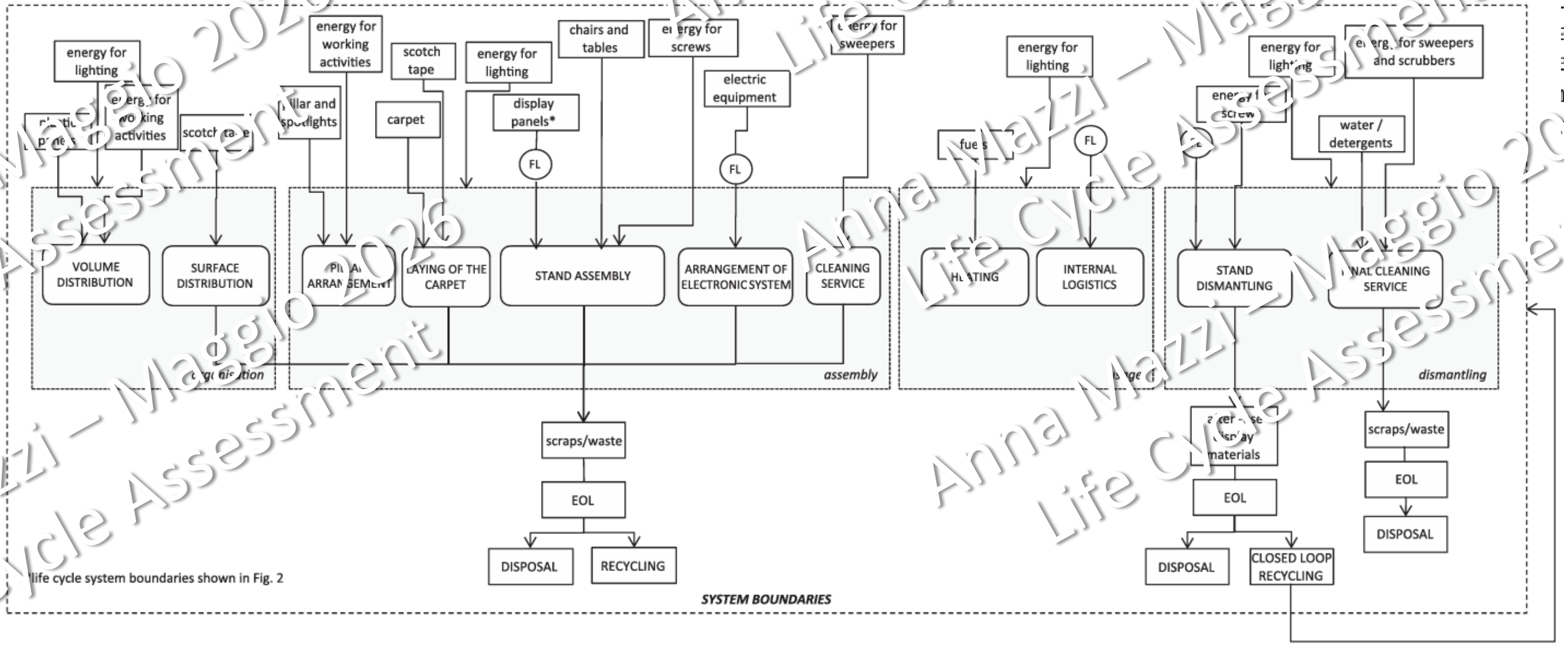
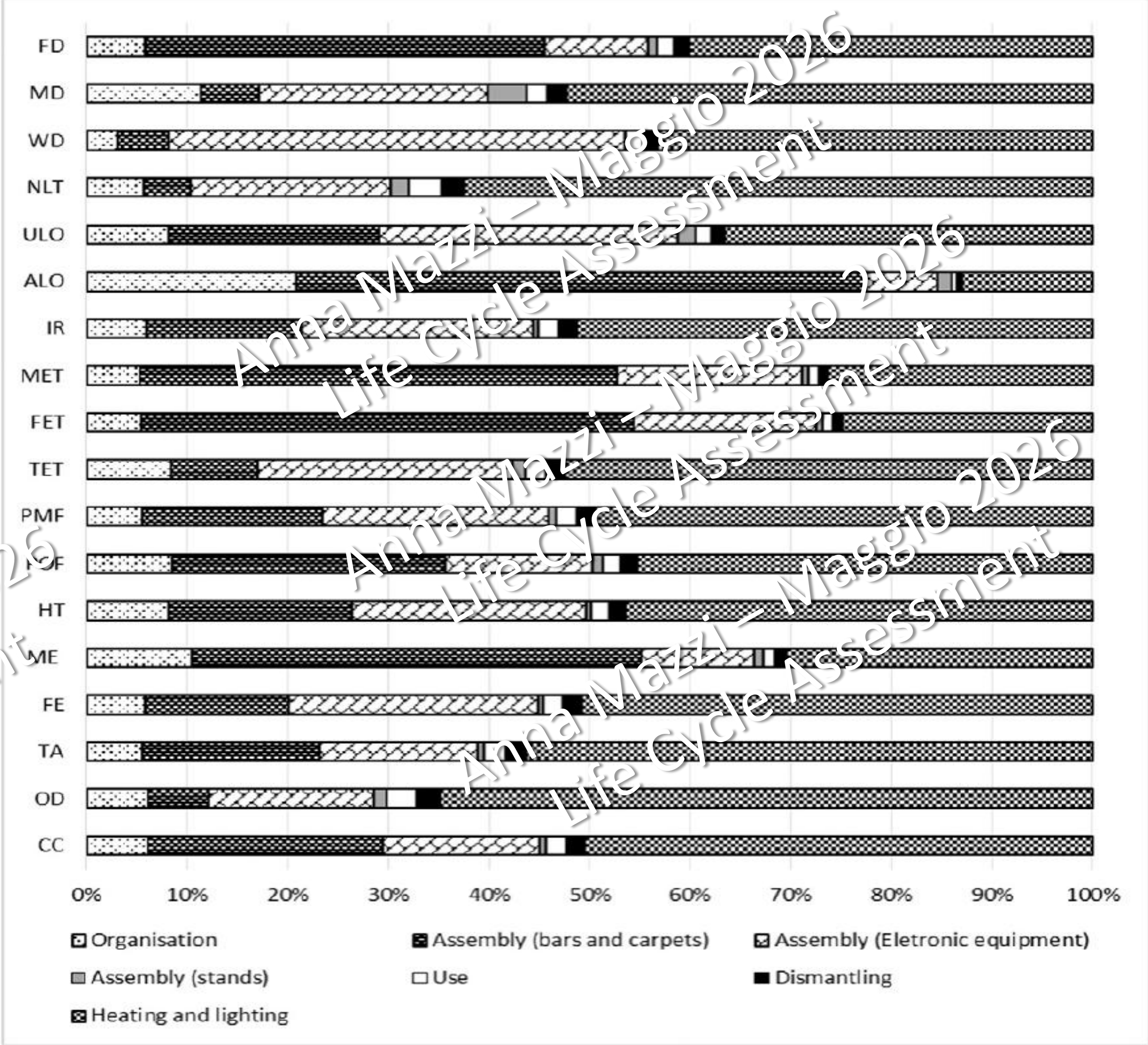


Fig. 1. System boundaries of the event under study (EOL: end-of-life; FL: forklifts).

Toniolo, Mazzi et al., 2017
http://dx.doi.org/10.1016/j.eiar.2016.07.007

LCA per identificare gli hotspot ambientali



Toniolo, Mazzi et al., 2017
Life Cycle Assessment to support tLife Cycle Assessment to support the quantification of the environmental impacts of an event
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LCA per identificare gli hotspot ambientali

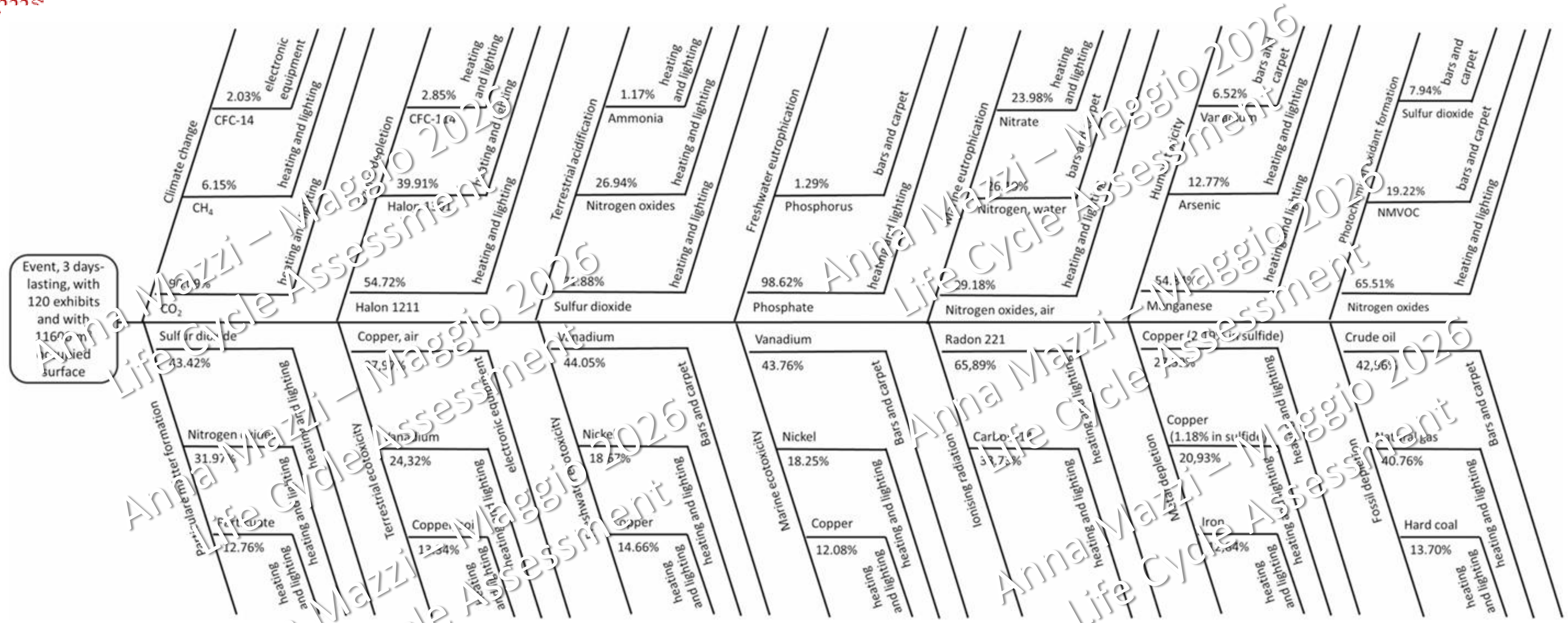


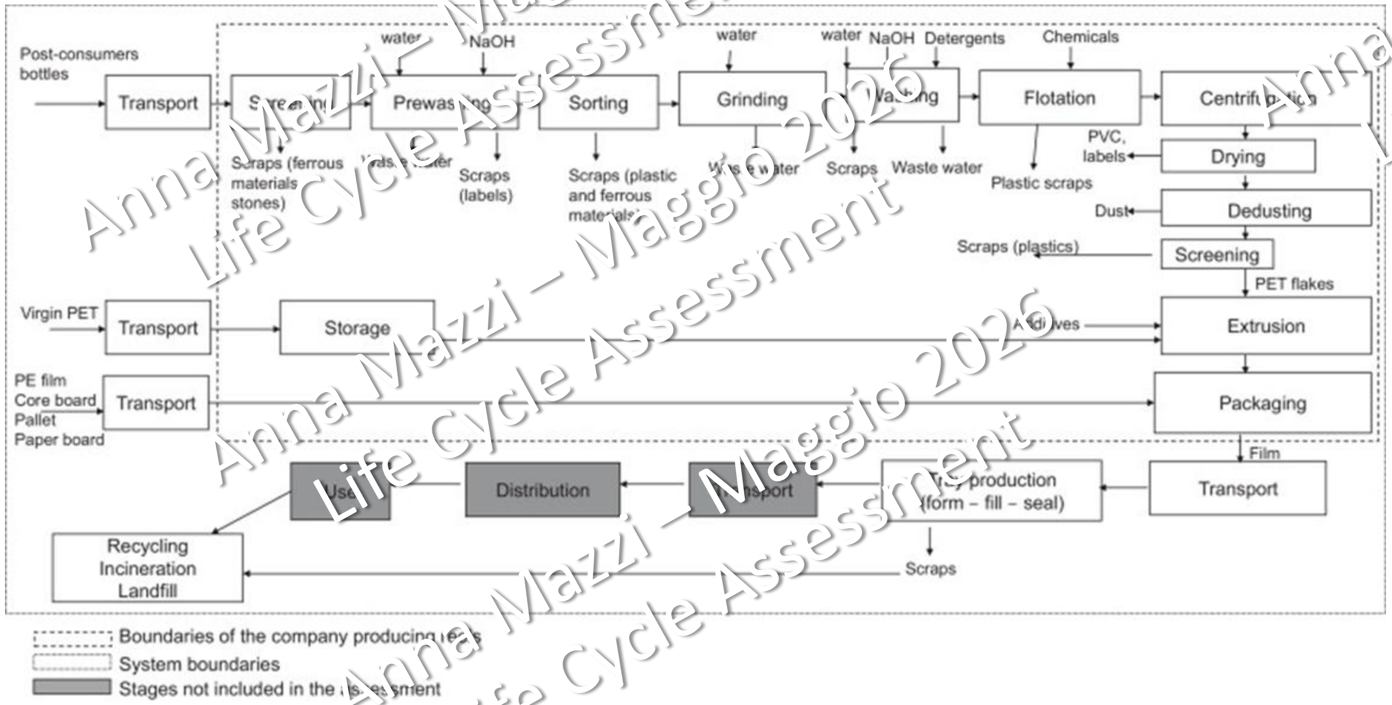
Fig. 4. Effects of the substances on some impact categories and the processes that generated them.

Toniolo, Mazzi et al., 2017
Life Cycle Assessment to support tLife Cycle Assessment to support the quantification of the environmental impacts of an event
http://dx.doi.org/10.1016/j.eiar.2016.07.007

LCA per guidare l'innovazione

Contents lists available at SciVerse ScienceDirect
Resources, Conservation and Recycling
journal homepage: www.elsevier.com/locate/resconrec

Comparative LCA to evaluate how much recycling is environmentally favourable for food packaging



A B S T R A C T

Plastic represents a significant fraction of the total packaging waste, and its management is an important issue that should embrace recycling techniques for material recovery. Support decisions in the area of waste management can be made using the life cycle approach, which is commonly used to identify the environmental impacts of recycling and can give information to put environmental issues into a wide perspective.

This study evaluates how much an innovative recyclable package is environmentally preferable to an alternative package that is not recyclable considering that both are produced from recycling post-consumer PET bottles.

Two products were chosen to perform the study. The first product is a package produced with a multilayer film and whose end-of-life scenario includes land-filling and incineration. The second product is an innovative package produced employing a mono-material whose end-of-life scenario comprises recycling, land-filling and incineration.

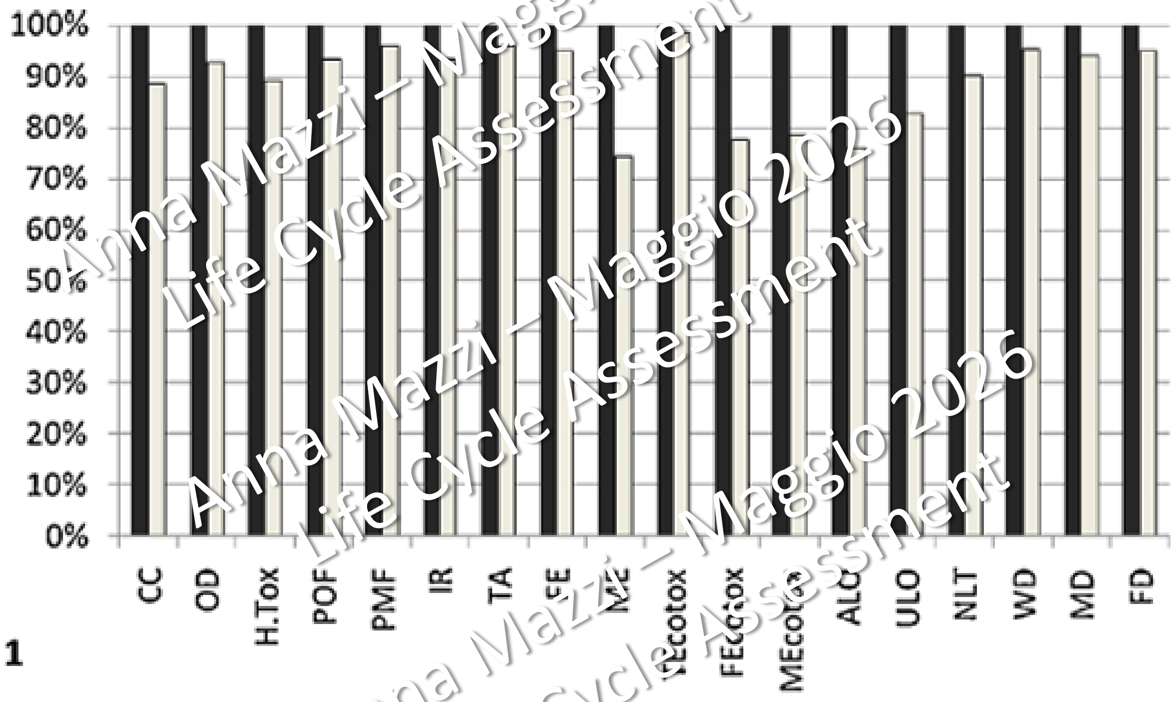
This study explains that the utilisation of recycled materials represents the initial effort to reduce environmental burdens and shows that using recycled materials combined with specific additives that assure the recyclability of the final product leads to a better environmental performance. The package produced employing a recyclable mono-material film is more environmental advisable than the multilayer for all of the impact categories analysed. The results obtained are also tested using a sensitivity analysis and an uncertainty analysis and confirm the results of the life cycle impact assessment. The study demonstrates the potentiality of the life cycle approach to assess whether a prevention activity to reduce waste production is actually environmental sustainable and to provide decision-making support in the field of packaging waste management.

Toniolo, Mazzi et al., 2013. Comparative LCA to evaluate how much recycling is environmentally favourable for food packaging
https://doi.org/10.1016/j.resconrec.2013.06.003

LCA per guidare l'innovazione

Risultati LCA dall'analisi di scenari per il plastic tray

1) scenari alternativi di fine vita (senza riciclo VS con riciclo)
2) diverse composizioni chimiche degli additivi (maggiore VS minore pericolosità)



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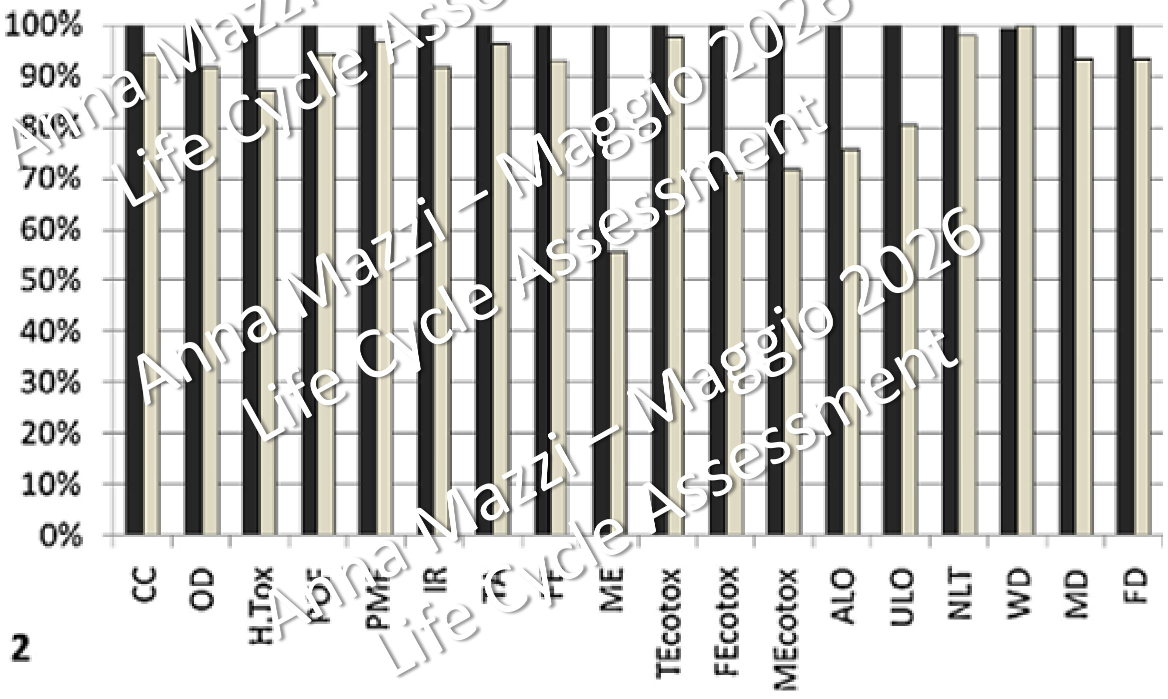

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Toniolo, Mazzi et al., 2013. Comparative LCA to evaluate how much recycling is environmentally favourable for food packaging
https://doi.org/10.1016/j.resconrec.2013.06.003

- Life Cycle Assessment: cos'è e perché
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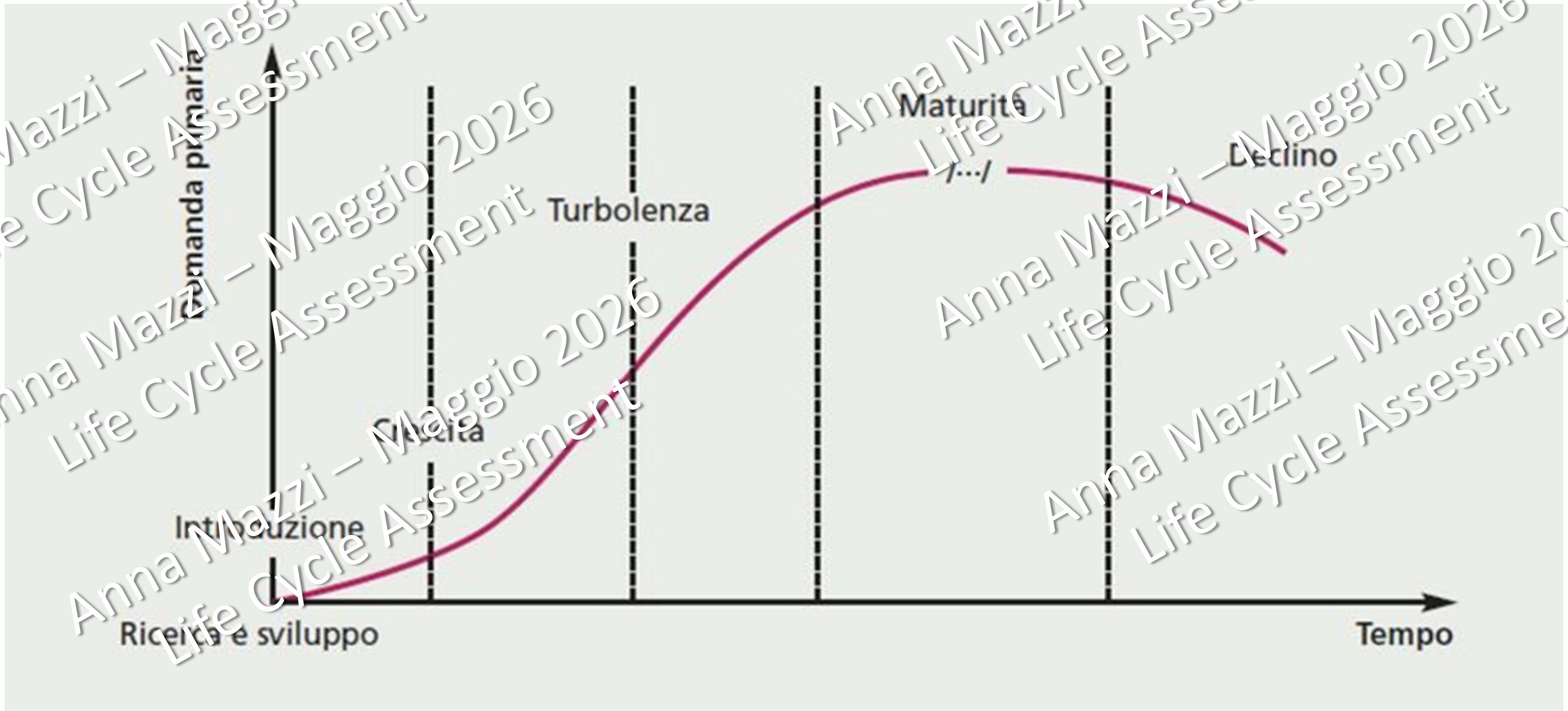
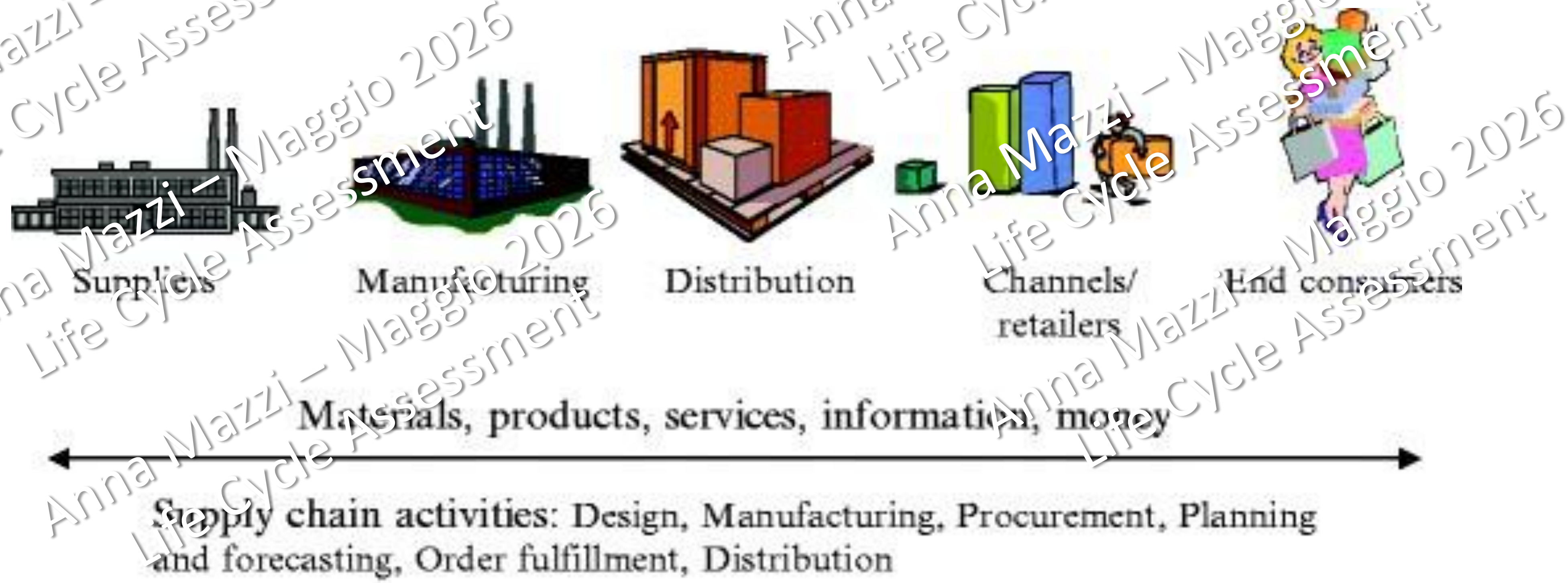
Concetto di «product life cycle» – le origini

Nelle scienze economiche, il ciclo di vita di un prodotto è un modello nato per rappresentare la risposta del mercato all'introduzione di un nuovo prodotto



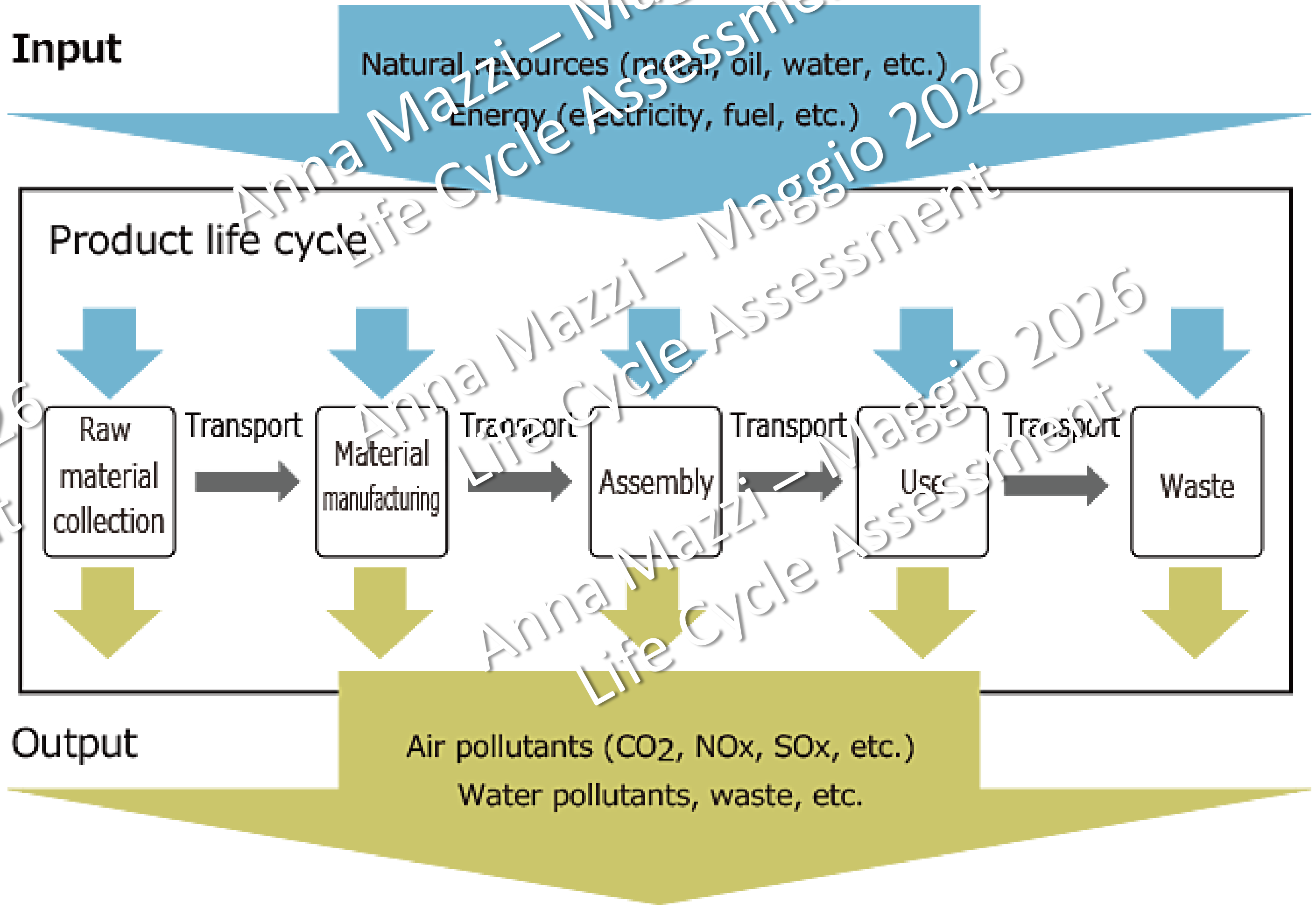
Concetto di «product life cycle» nel management aziendale

Nel **Supply Chain Management** rappresenta le relazioni operative e commerciali tra i diversi attori della filiera – catena di fornitura – per ottenere la realizzazione e distribuzione dei beni e servizi sul mercato



Concetto di «product life cycle» in campo ambientale

È più **conveniente** e più **efficace** tener conto di tutti i carichi ambientali del ciclo di vita di un prodotto o servizio per individuare dove è più **opportuno** intervenire per migliorare le **prestazioni ambientali complessive**



LCA – le origini

Primi studi nel 1969 commissionati dalla Coca Cola per capire quale poteva essere il migliore contenitore possibile per bevande

- Qual è il packaging con il minore impatto ambientale? Vetro, lattina o plastica?
- Quale packaging è più adatto a essere riutilizzato dopo l'uso?
- Qual è la migliore strategia di gestione a fine vita? «a rendere» o «a perdere»?

Dal Life Cycle Thinking al Life Cycle Assessment

70s: first studies

- Goals: resource use, energy efficiency, input-output analysis
- Focus on environmental aspects: raw materials consumption, waste production

80s-90s: spread and development

- Goals: hotspot analysis and environmental accountability
- Focus: energy consumption, environmental impacts, human health damage

1992: boom

- UN Earth Summit: «LCA is among the most promising new tools for a wide range of environmental management tasks»

Since 2005: European Policy supports the adoption of LCA in many industrial sectors

- Integrated Product Policy
- Environmental Product Labelling
- Sustainable Production and Consumption
- Circular Economy
- End of Waste

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Standard ISO per il Life Cycle Assessment

ISO/TC 207 SC 5 - Life Cycle Assessment https://www.iso.org/committee/54854.html

ISO 14040:2006

Environmental management — Life cycle assessment — Principles and framework

Published (Edition 2, 2006)
This standard was last reviewed and confirmed in 2022. Therefore this version remains current.

ISO 14044:2006

Environmental management — Life cycle assessment — Requirements and guidelines

Published (Edition 1, 2006)
This standard was last reviewed and confirmed in 2022. Therefore this version remains current.

↳ This standard has 2 amendments.

19	1	59	25
Published ISO standards	ISO standard under development	Participating members	Observing members

ISO/TC 207/SC 5/AHG	Scope revision
ISO/TC 207/SC 5/JWG 14	Joint ISO/TC 207/SC 5 - ISO/TC 323 WG: Secondary materials
ISO/TC 207/SC 5/TG 2	Circular economy coordination
ISO/TC 207/SC 5/WG 12	Life cycle assessment -- Requirements and guidelines
ISO/TC 207/SC 5/WG 15	Social life cycle assessments
ISO/TC 207/SC 5/WG 16	Eco-Technoeconomic Analyses

Joint working groups under the responsibility of another committee

ISO/TC 207/SC 3/TF 3	Assurance of communications based on life cycle assessment (LCA) data

Standard ISO per la sostenibilità ambientale

ISO/TC 207
Environmental Management

57 PUBLISHED ISO STANDARDS related to the TC and its SCs — of which 5 under the direct responsibility of ISO/TC 207

18 ISO STANDARDS UNDER DEVELOPMENT related to the TC and its SCs

81 PARTICIPATING MEMBERS

42 OBSERVING MEMBERS

ISO 14040
ISO 14044
ISO 14045
ISO 14072
…

ISO 14001
ISO 14004
ISO 14031
ISO 14033
ISO 14034
ISO 14063
…

ISO 14020
ISO 14021
ISO 14024
ISO 14025
ISO 14027
…

ISO 14006

ISO 14062

ISO 14046

ISO 14064
ISO 14067
ISO 14069
…

https://www.iso.org/committee/54808.html

Altri standard ISO con approccio LCA

https://www.iso.org/committee/54808.html

Reference ↑	Title
ISO/TC 207/SC 1	Environmental management systems
ISO/TC 207/SC 2	Environmental auditing and related environmental investigations
ISO/TC 207/SC 3	Environmental labelling
ISO/TC 207/SC 4	Environmental performance evaluation
ISO/TC 207/SC 5	Life cycle assessment
ISO/TC 207/SC 7	Greenhouse gas and climate change management and related activities
ISO/TC 207/DCCG ⓘ	Developing Countries Coordination Group
ISO/TC 207/SLG ⓘ	Strategic Leadership Group
ISO/TC 207/STTF ⓘ	Spanish translation task force
ISO/TC 207/TCG ⓘ	Terminology Coordination Group
ISO/TC 207/TF 1 ⓘ	Communications
ISO/TC 207/TG 1 ⓘ	Sustainable Finance Coordination
ISO/TC 207/TG 2 ⓘ	Circular economy coordination

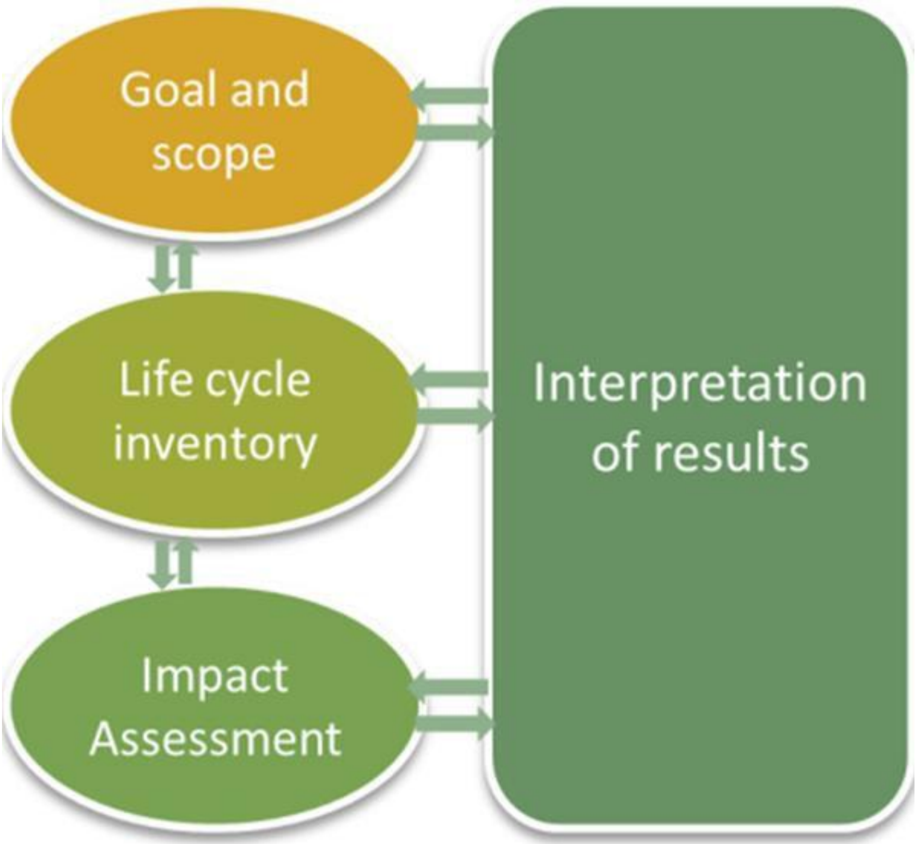
Fasi della metodologia LCA (highlights)

ISO 14040
Principi e quadro di riferimento

ISO 14044 – § 4.2

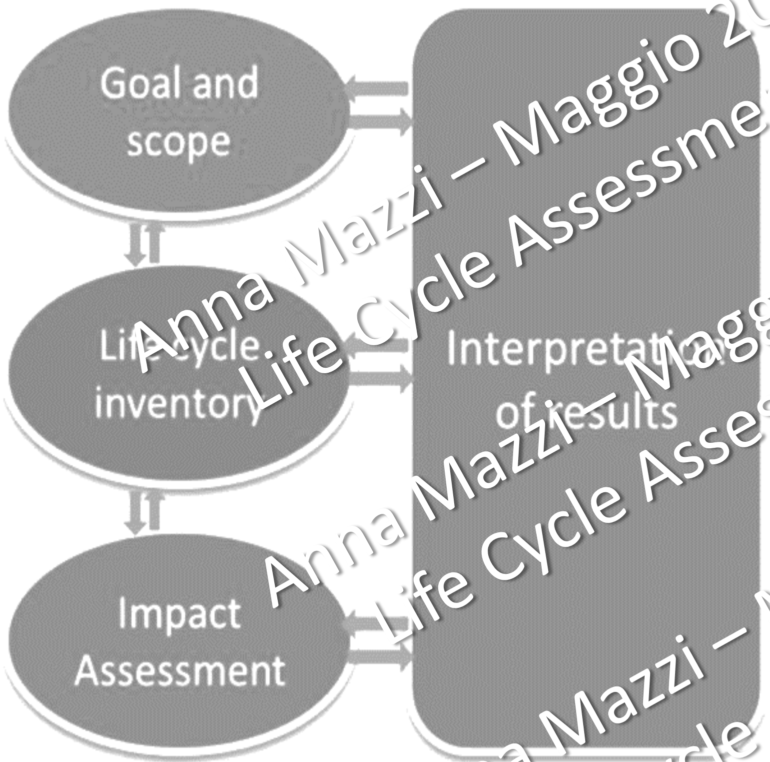
ISO 14044 – § 4.3

ISO 14044 – § 4.4



ISO 14044 – § 4.5

Fasi di uno studio di LCA (highlights)



1. Goal and Scope: definire cosa studiare, perché ottenere il profilo di impatto ambientale, come strutturare lo studio

   Funzione e unità funzionale, destinatari, confini del sistema, qualità dei dati, …

2. Life Cycle Inventory: ottenere l'inventario dei flussi in entrata e in uscita di materia ed energia

   Identificazione dei processi, raccolta dati, correlazione, aggregazione, …

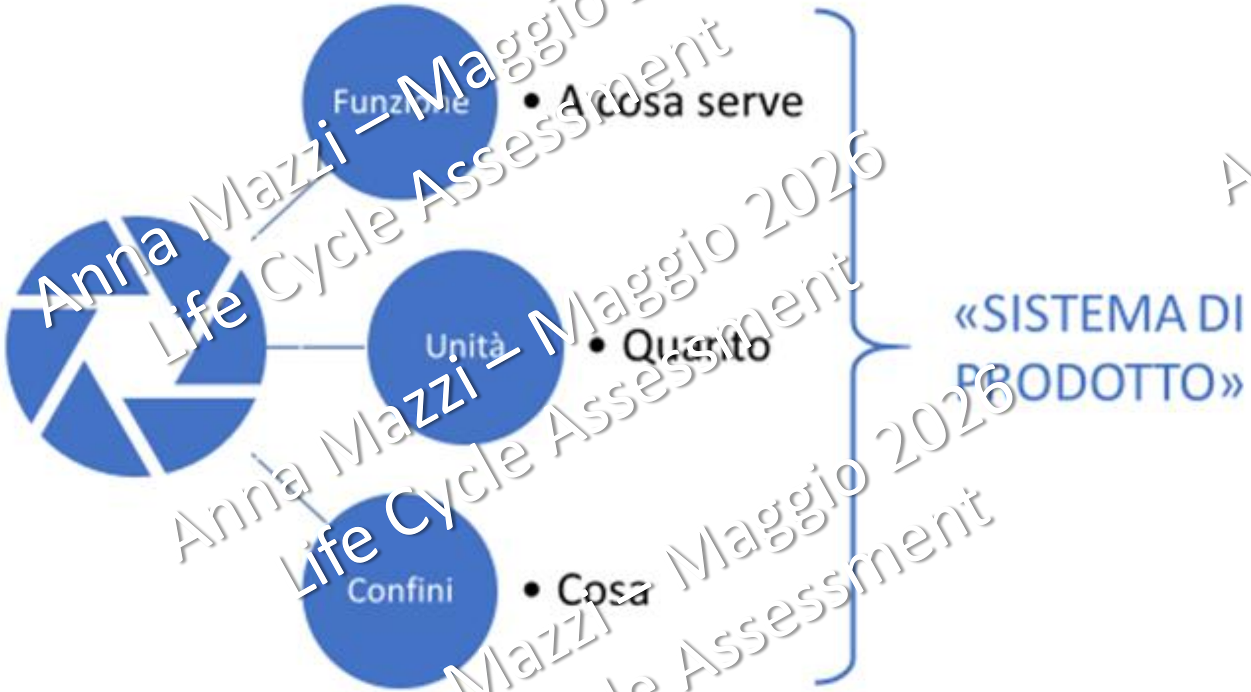
3. Life Cycle Impact Assessment: quantificare gli impatti ambientali associati ai singoli flussi

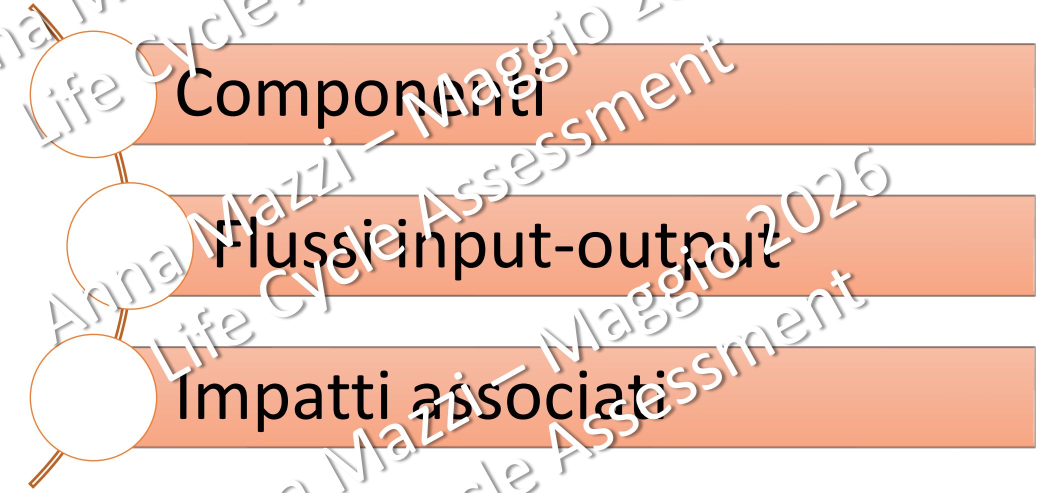
   Selezione dei modelli di valutazione, classificazione, caratterizzazione, …

4. Interpretation of results: comprendere la rilevanza ambientale di fasi, processi, materiali, sostanze, opzioni

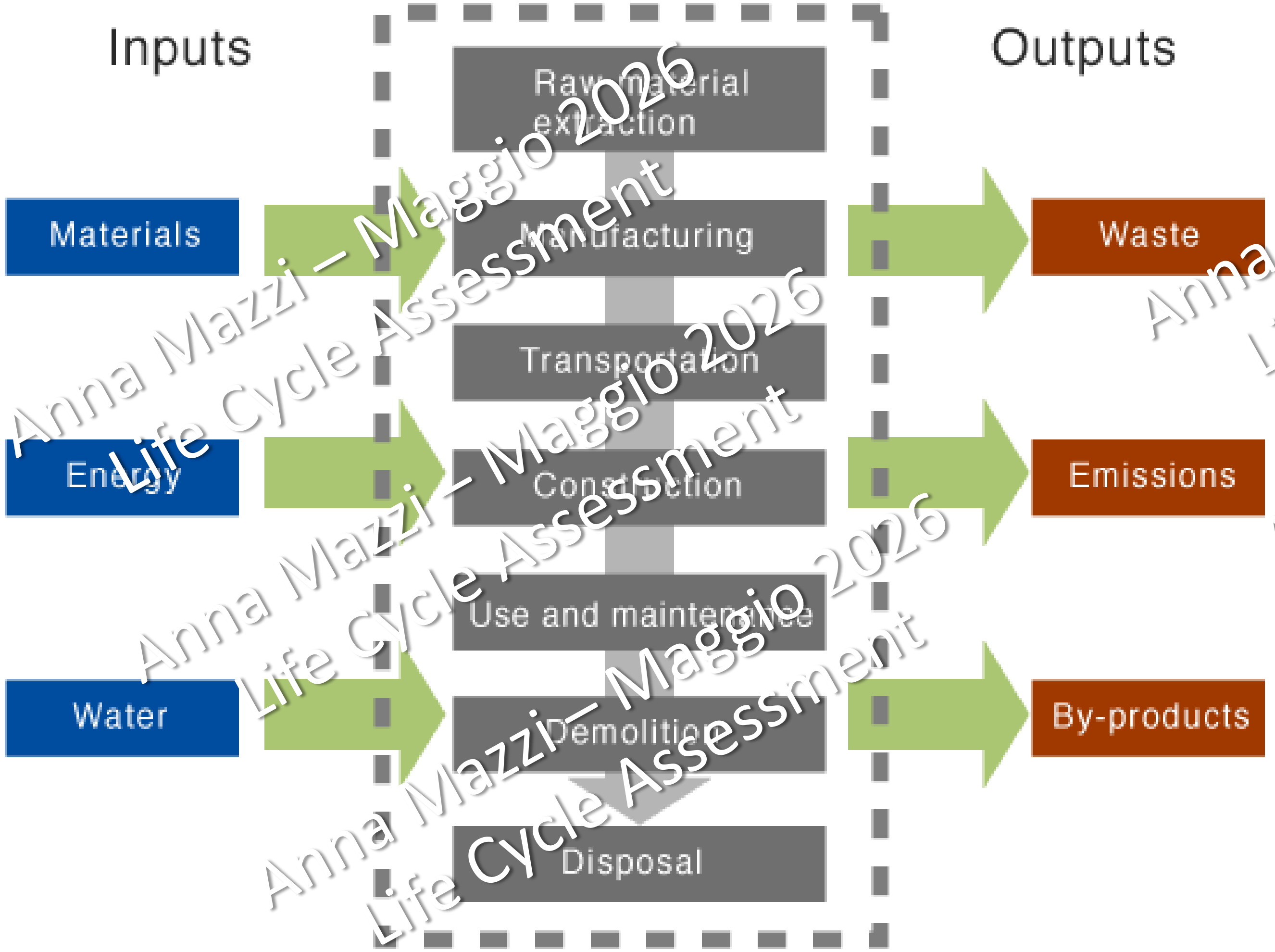
   Analisi dei contributi, verifica di consistenza, sensibilità e incertezza, conclusioni e raccomandazioni

Cosa definire come campo di applicazione dello studio LCA (Scope)





Cosa considerare nello studio di LCA (Life Cycle Inventory)

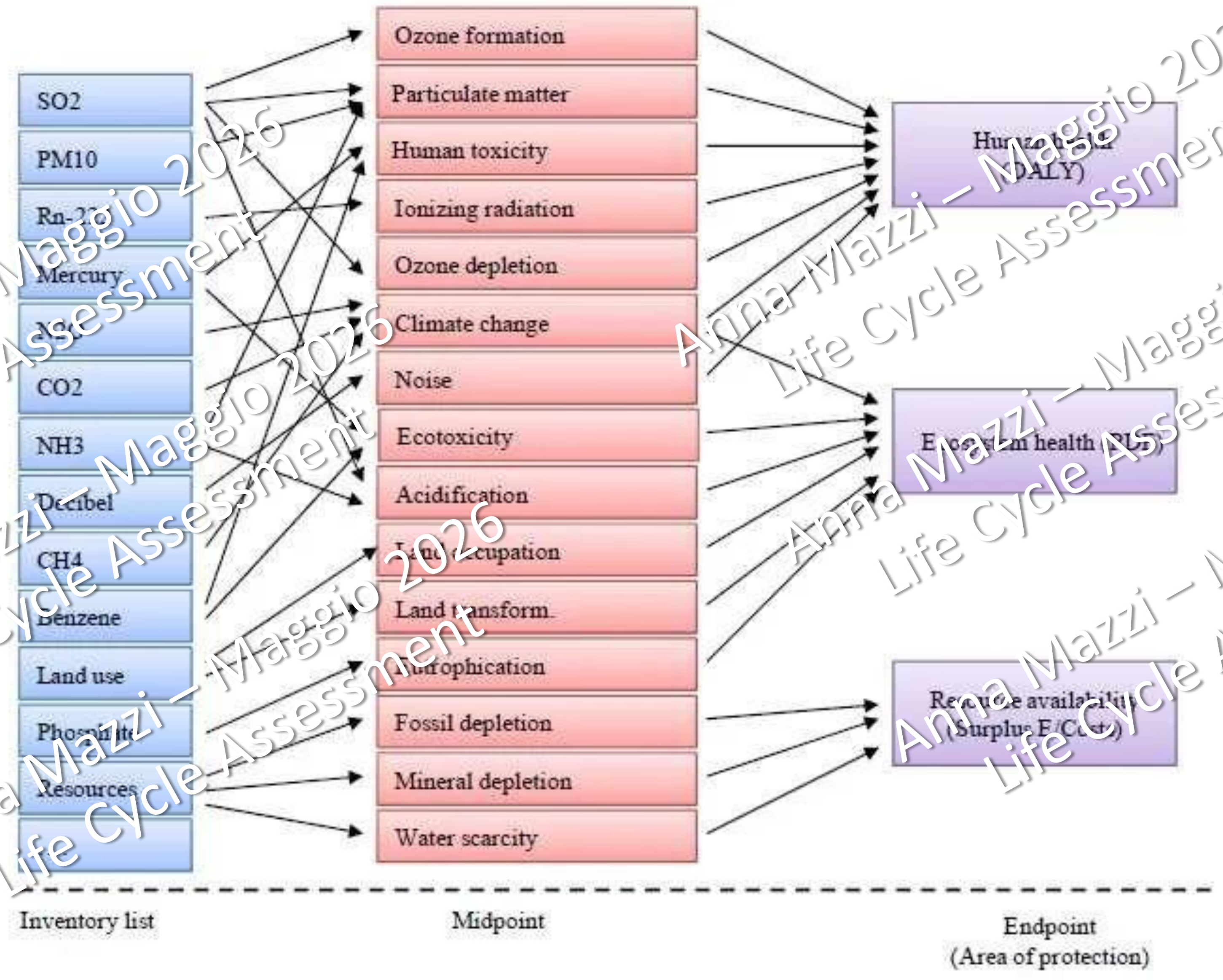


Compilazione e valutazione attraverso tutto il ciclo di vita dei flussi in entrata e in uscita del sistema di prodotto

$$x_i = y_i + \sum_j X_{ij}$$

BILANCIO DI INPUT E OUTPUT DI MATERIA ED ENERGIA

Come quantificare gli impatti ambientali (Impact Assessment)



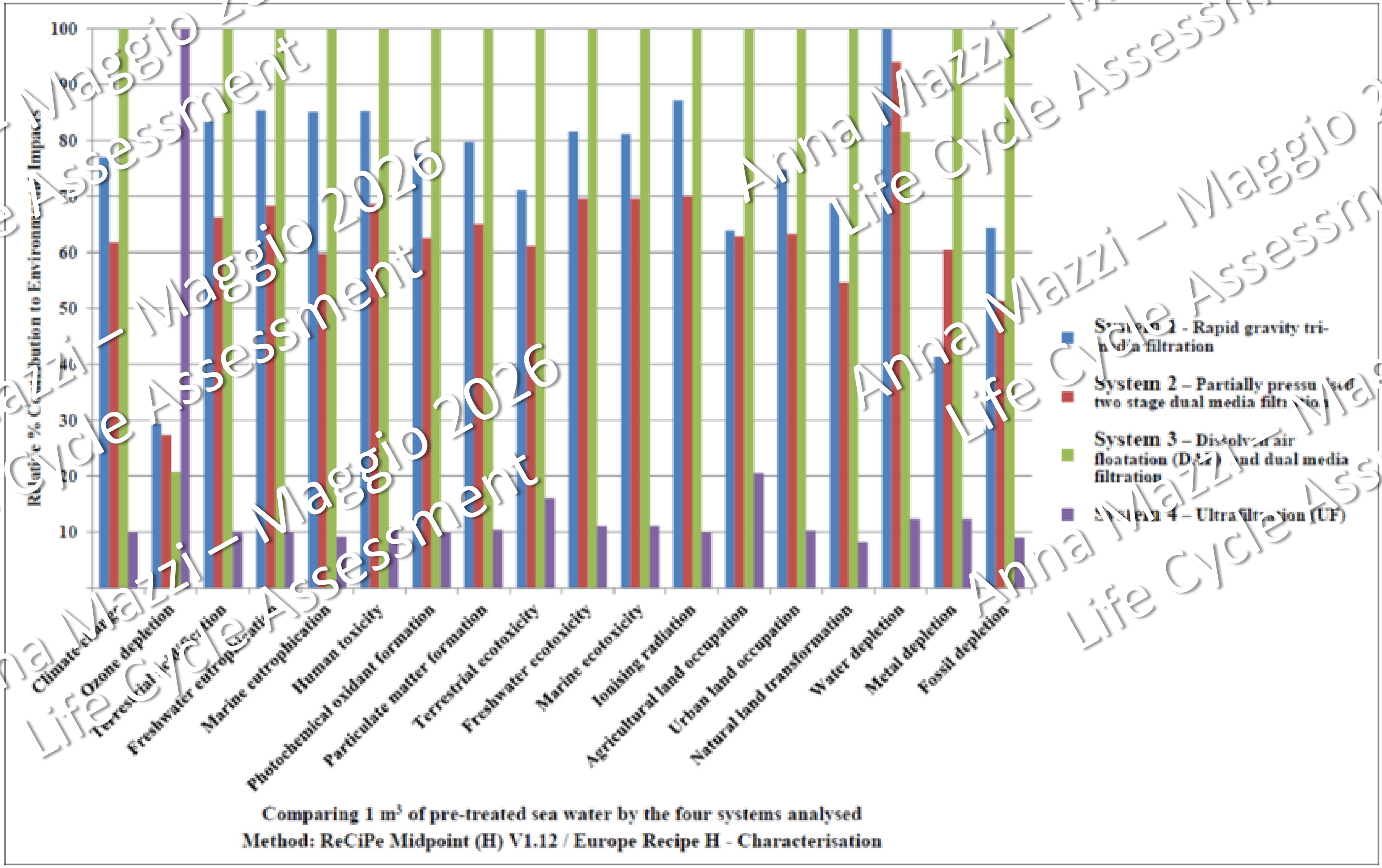
Esempi di categorie di impatto e indicatori di impatto

mpact category / Indicator	Unit	Description
Climate change – total, fossil, biogenic and land use	kg CO_2-eq	Indicator of potential global warming due to emissions of greenhouse gases to air. Divided into 3 subcategories based on the emission source: (1) fossil resources, (2) bio-based resources and (3) land use change.
Ozone depletion	kg CFC-11-eq	Indicator of emissions to air that cause the destruction of the stratospheric ozone layer
Acidification	kg mol H+	Indicator of the potential acidification of soils and water due to the release of gases such as nitrogen oxides and sulphur oxides
Eutrophication – freshwater	kg PO_4-eq	indicator of the enrichment of the fresh water ecosystem with nutritional elements, due to the emission of nitrogen or phosphor containing compounds
Eutrophication – marine	Kg N-eq	Indicator of the enrichment of the marine ecosystem with nutritional elements, due to the emission of nitrogen containing compounds.
Eutrophication – terrestrial	mol N-eq	Indicator of the enrichment of the terrestrial ecosystem with nutritional elements, due to the emission of nitrogen containing compounds.
Photochemical ozone formation	kg NMVOC-eq	Indicator of emissions of gases that affect the creation of photochemical ozone in the lower atmosphere (smog) catalysed by sunlight.
Depletion of abiotic resources – minerals and metals	kg Sb-eq	Indicator of the depletion of natural non-fossil resources.
Depletion of abiotic resources – fossil fuels	MJ, net calorific value	Indicator of the depletion of natural fossil fuel resources.
Human toxicity – cancer, non-cancer	CTUh	Impact on humans of toxic substances emitted to the environment. Divided into non-cancer and cancer related toxic substances.
Eco-toxicity (freshwater)	CTUe	Impact on freshwater organisms of toxic substances emitted to the environment.
Water use	m3 world eq. deprived	Indicator of the relative amount of water used, based on regionalized water scarcity factors.
Land use	Dimensionless	Measure of the changes in soil quality (Biotic production, Erosion resistance, Mechanical filtration).
Ionising radiation, human health	kBq U-235	Damage to human health and ecosystems linked to the emissions of radionuclides.
Particulate matter emissions	Disease incidence	Indicator of the potential incidence of disease due to particulate matter emissions.

NB: Requisiti aggiuntivi per LCA comparativi

Negli **studi comparativi** deve sempre essere assicurata l'**EQUIVALENZA** dei sistemi posti a confronto

Tutte le scelte metodologiche e operative devono essere equivalenti



Come condurre uno studio di LCA: esempio «LIFE chair»

Sustainability Assessment and Management
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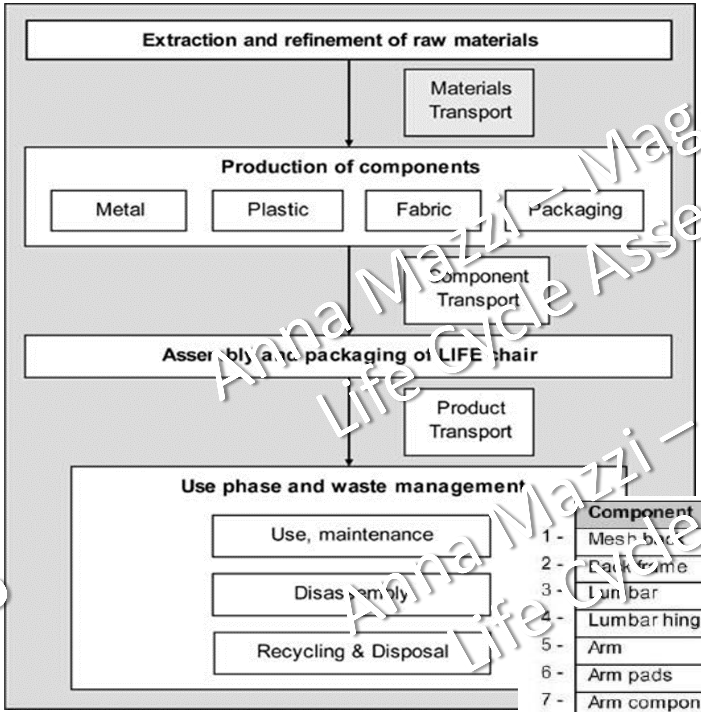
Int J Life Cycle Assess (2008) 13:401–411
DOI 10.1007/s11367-008-0002-3

CASE STUDY

Life cycle assessment of commercial furniture: a case study of Formway LIFE chair

Abstract

Background, aims and scope The environmental aspects of companies and their products are becoming more significant in delivering competitive advantage. Formway Furniture, a designer and manufacturer of office furniture products, is a New Zealand-based company that is committed to sustainable development. It manufactures two models of the light, intuitive, flexible and environmental (LIFE) office chair: one with an aluminium base and one with a glass-filled nylon (GFN) base. It was decided to undertake a life cycle assessment (LCA) study of these two models in order to: (1) determine environmental hotspots in the life cycle of the two chairs (goal 1); (2) compare the life cycle impacts of the two chairs (goal 2); and (3) compare alternative potential waste-management scenarios (goal 3). The study also included sensitivity analysis with respect to recycled content of aluminium in the product.



Goal & Scope

	Component	Material
1 -	Mesh back	Polyester
2 -	Back frame	Glass filled nylon
3 -	Lumbar	ABS
4 -	Lumbar hinge	Nylon
5 -	Arm	Aluminium
6 -	Arm pads	Polyurethane foam
7 -	Arm components	Acetal
8 -	Seat cushion	Polyurethane foam
9 -	Seat moulding	Hytrel Crastin(PBT)
10 -	Seat carriage	Aluminium
11 -	Mechanism assembly	Aluminium
12 -	Gas spring tube	Steel
13 -	Base	Nylon / aluminium
14 -	Castors	Nylon
15 -	Castor axle, spring	Zinc
	Springs, bolts, pivots	Steel

Gamage et al., 2008. Life cycle assessment of commercial furniture: a case study of Formway LIFE chair.
DOI 10.1007/s11367-008-0002-3

Come condurre uno studio di LCA: esempio «LIFE chair»

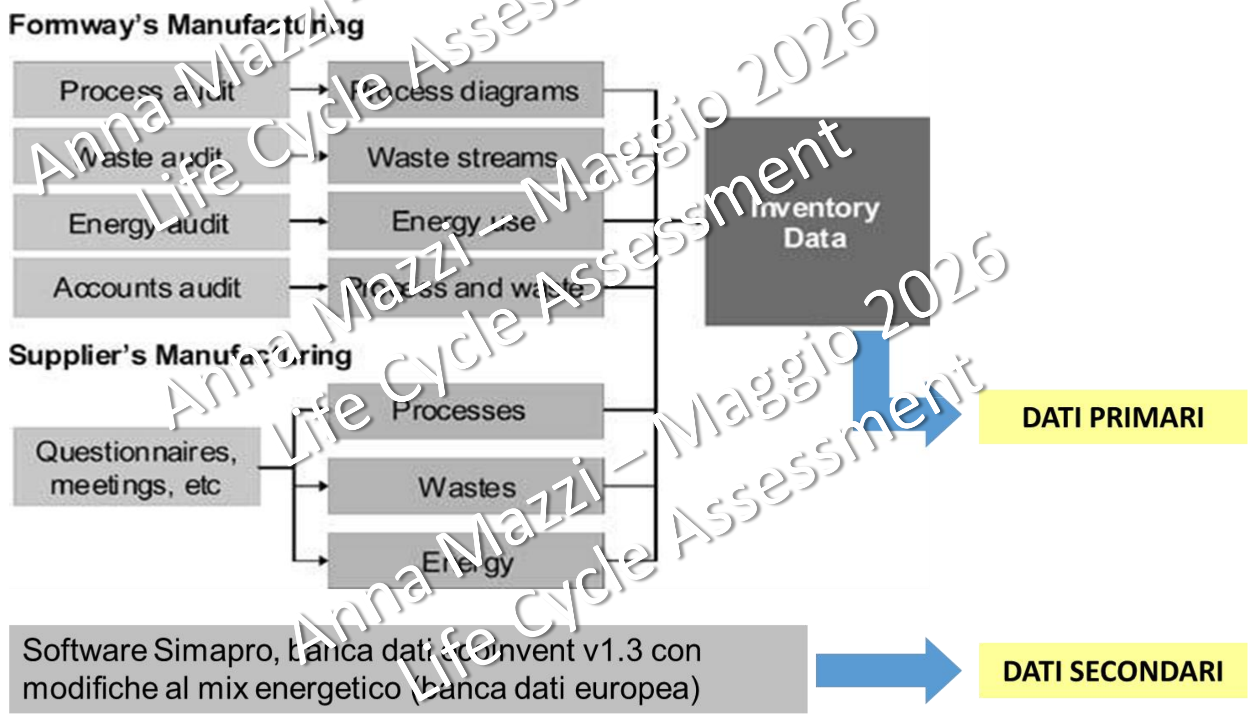
Goal & Scope

Inventory

- La **funzione** della sedia LIFE è quella di fornire supporto a sedere stabile, ergonomico, per una postazione di lavoro da ufficio
- L'**unità funzionale** di una sedia LIFE è stata definita come la fornitura di sedie per ufficio confortevoli, con le caratteristiche indicate nella descrizione del prodotto considerata su un periodo di 10 anni, in linea con la garanzia sul prodotto

Assunzioni per LCA comparativo (equivalenza degli studi):

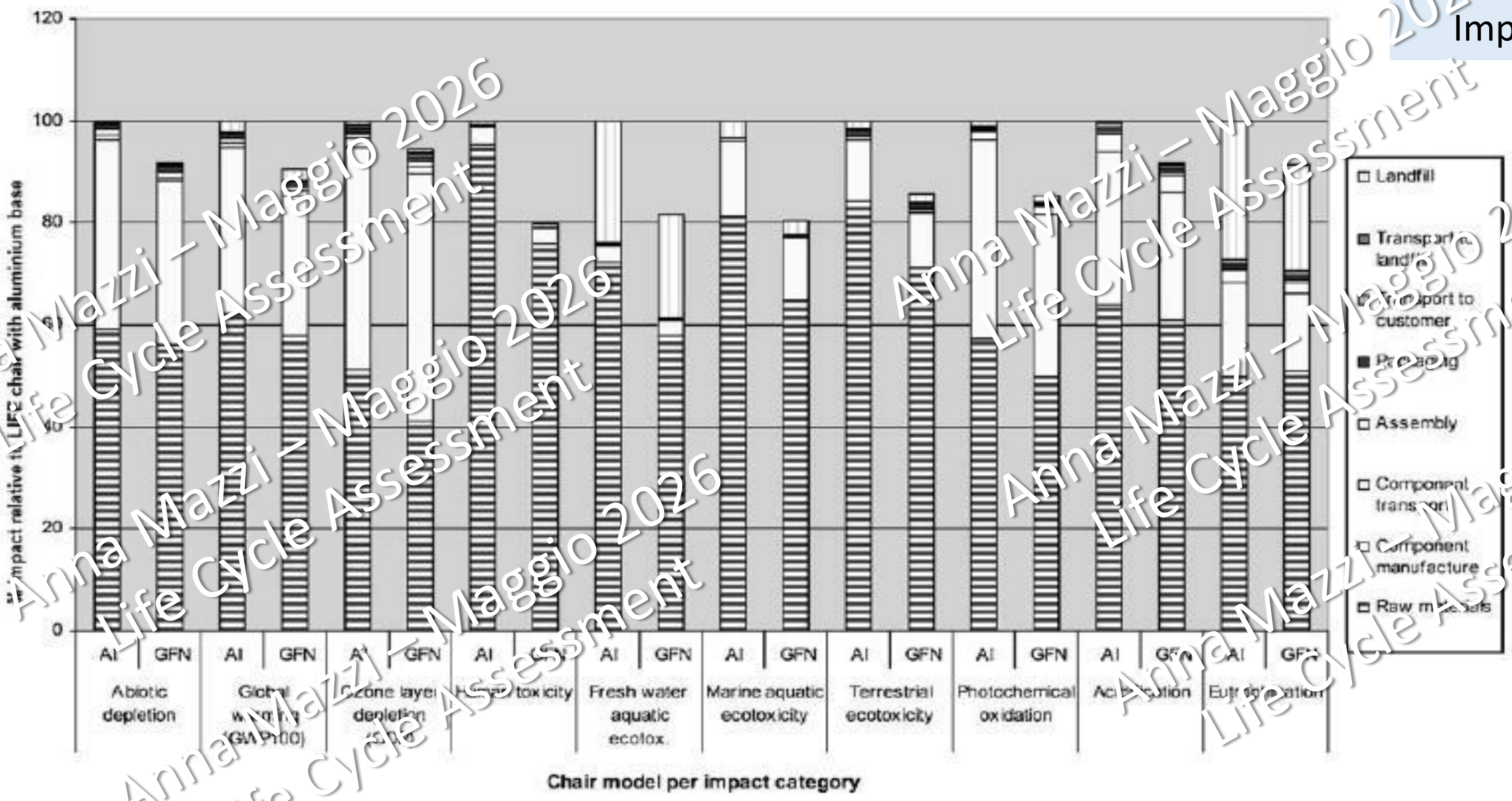
- Alluminio con **contenuto medio mondiale** di materiale riciclato, pari al **34%**
- Contenuto medio di materiale riciclato del **20%** per i componenti in acciaio
- Utilizzo del **PET** (Polietilentereftalato) al posto del **Hytrel-Crastin** (resina poliestere), supponendo che abbia effetti ambientali simili
- Il cliente è ipotizzato situato a Sydney, Australia, in quanto ciò rappresenta uno **scenario medio per il trasporto**



Gamage et al., 2008. Life cycle assessment of commercial furniture: a case study of Formway LIFE chair.
DOI 10.1007/s11367-008-0002-3

Come condurre uno studio di LCA: esempio «LIFE chair»

Impact Assessment

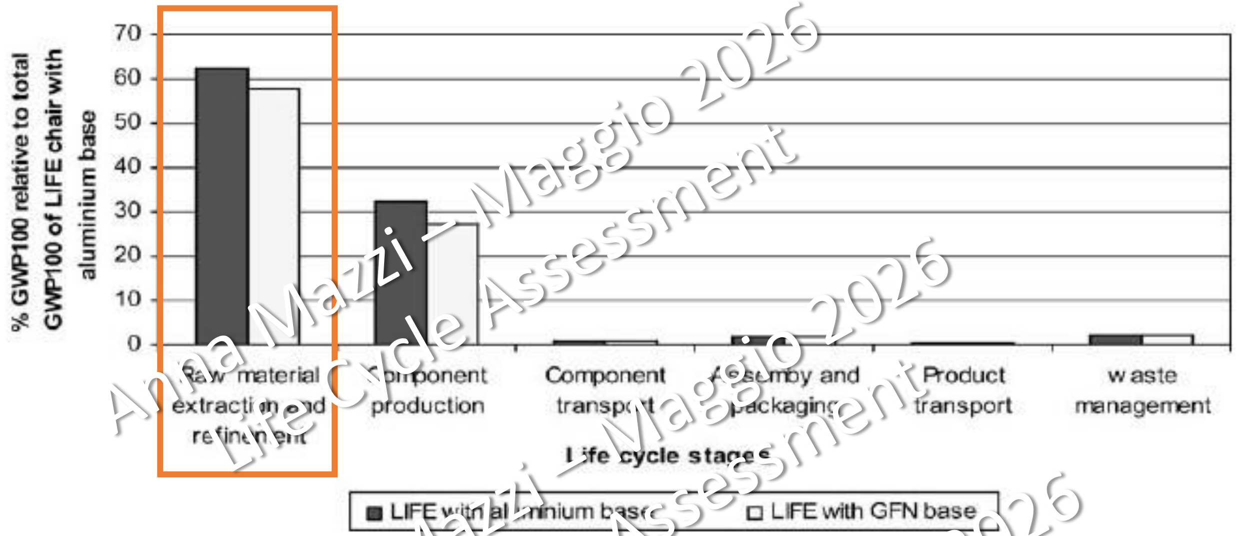


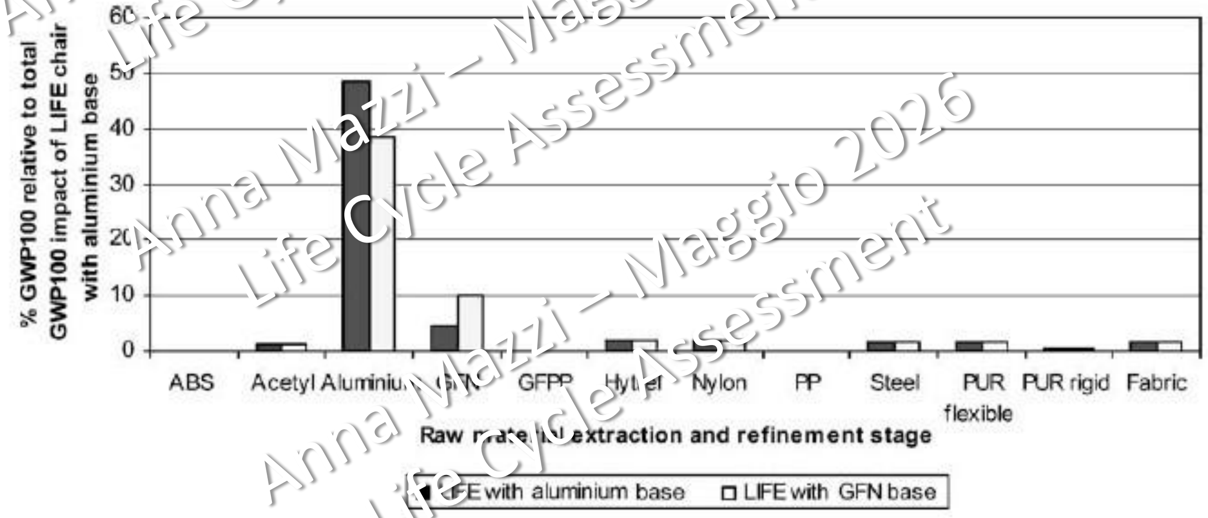
Gamage et al., 2008. Life cycle assessment of commercial furniture: a case study of Formway LIFE chair.
DOI 10.1007/s11367-008-0002-3

Come condurre uno studio di LCA: esempio «LIFE chair»

Ipotesi: Contenuto medio di Al riciclato (34%)

Interpretation





Gamage et al., 2008. Life cycle assessment of commercial furniture: a case study of Formway LIFE chair.
DOI 10.1007/s11367-008-0002-3

- Life Cycle Assessment: cos’è e perché
- Life Cycle Assessment: come e quando
- Life Cycle Assessment: opportunità e limiti
  - Riferimenti metodologici
  - Esempi e casi studio

LCA – possibili applicazioni

Gestione ambientale e miglioramento dei processi

- Analisi dei carichi ambientali nella supply chain
- Riduzione del consumo di materie prime, semilavorati, energia

Ecodesign e supporto alle decisioni

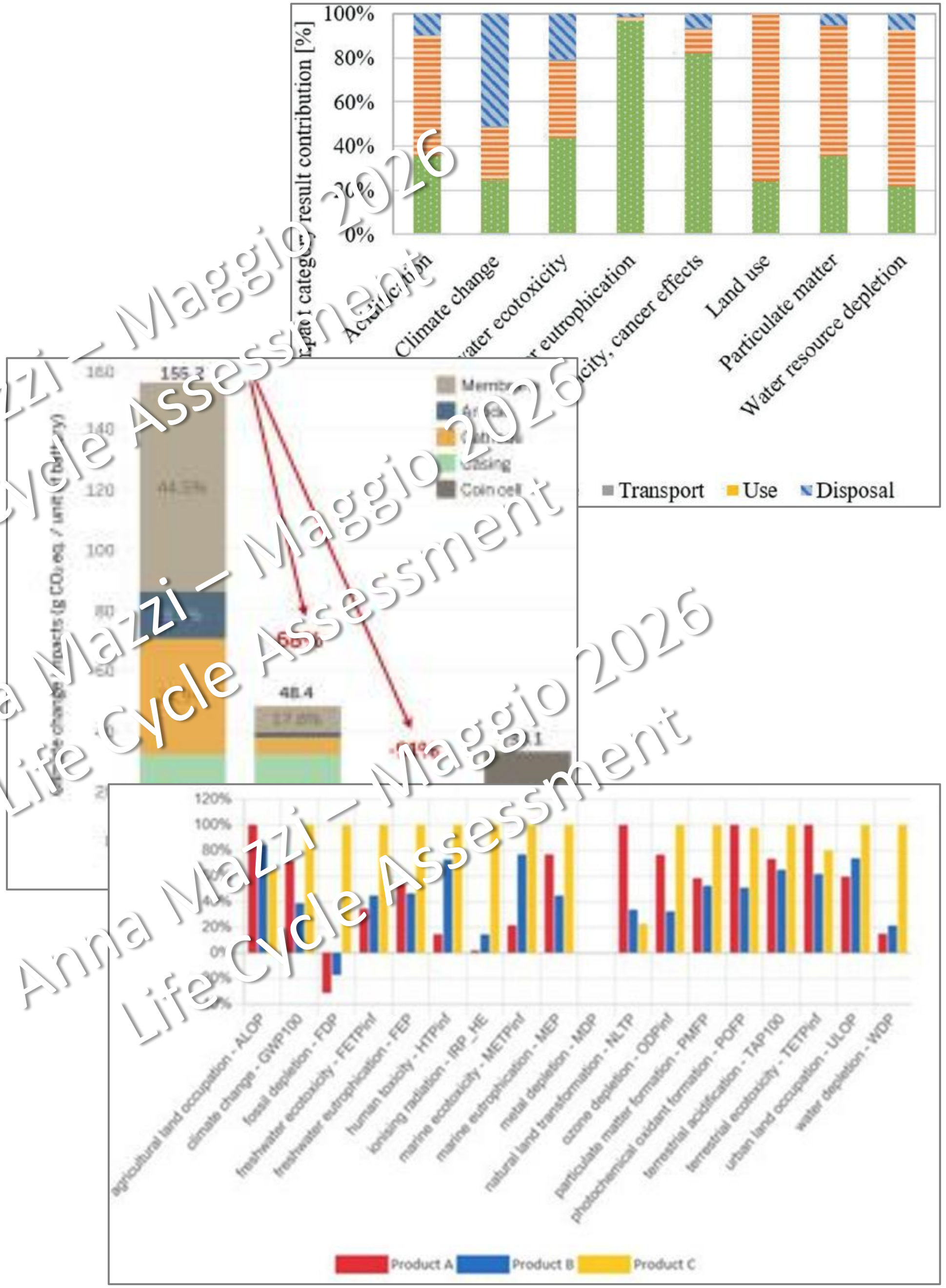
- Ricerca di soluzioni innovative di prodotti/servizi
- Progettazione di prodotti riutilizzabili, recuperabili, riciclabili

Marketing e green claims

- Comunicazione delle prestazioni ambientali dei prodotti
- Benchmarking con i competitors e con il mercato

Gestione ambientale strategica

- Gestione territoriale di rifiuti e risorse
- Gestione della transizione energetica



LCA per identificare le responsabilità ambientali

Journal of Cleaner Production 316 (2021) 128314

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Life cycle assessment for a grid-connected multi-crystalline silicon photovoltaic system of 3 kWp: A case study for Mexico

Highlights

- A Life-Cycle Assessment of a Grid-Connected Multi-crystalline Silicon Photovoltaic System of 3 kWp was carried out.
- Environmental impacts of production, installation, operation, and end-of-life stages were comprehensively analysed.
- Major environmental burdens come from the production stage of the solar PV modules.
- Lower environmental impacts were obtained from mc-Si PV systems in comparison with other systems (sc-Si, a-Si, and CIS).
- A strategic mapping of circular economy 'hot spots' across the technological value chain of PV systems is still needed.

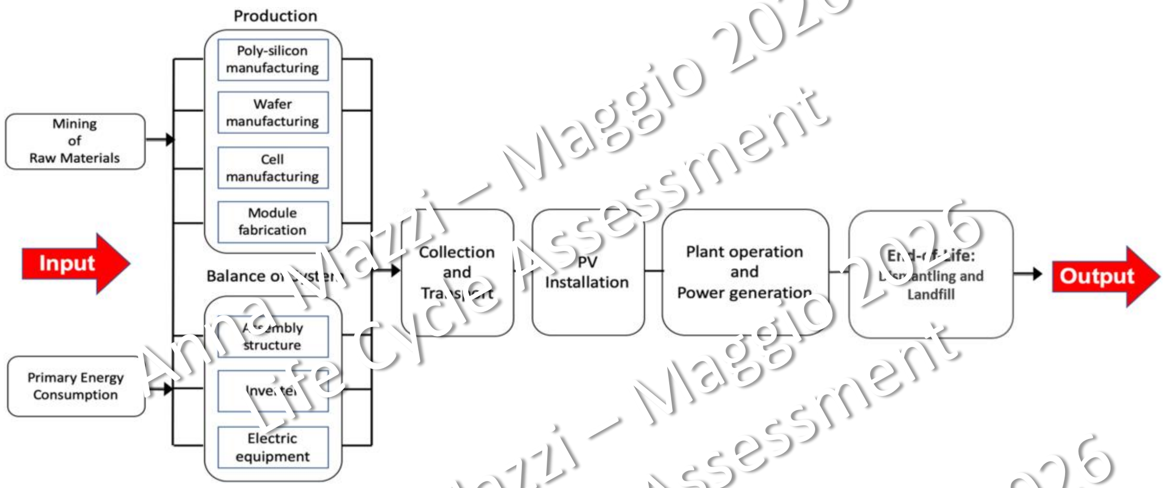
A B S T R A C T

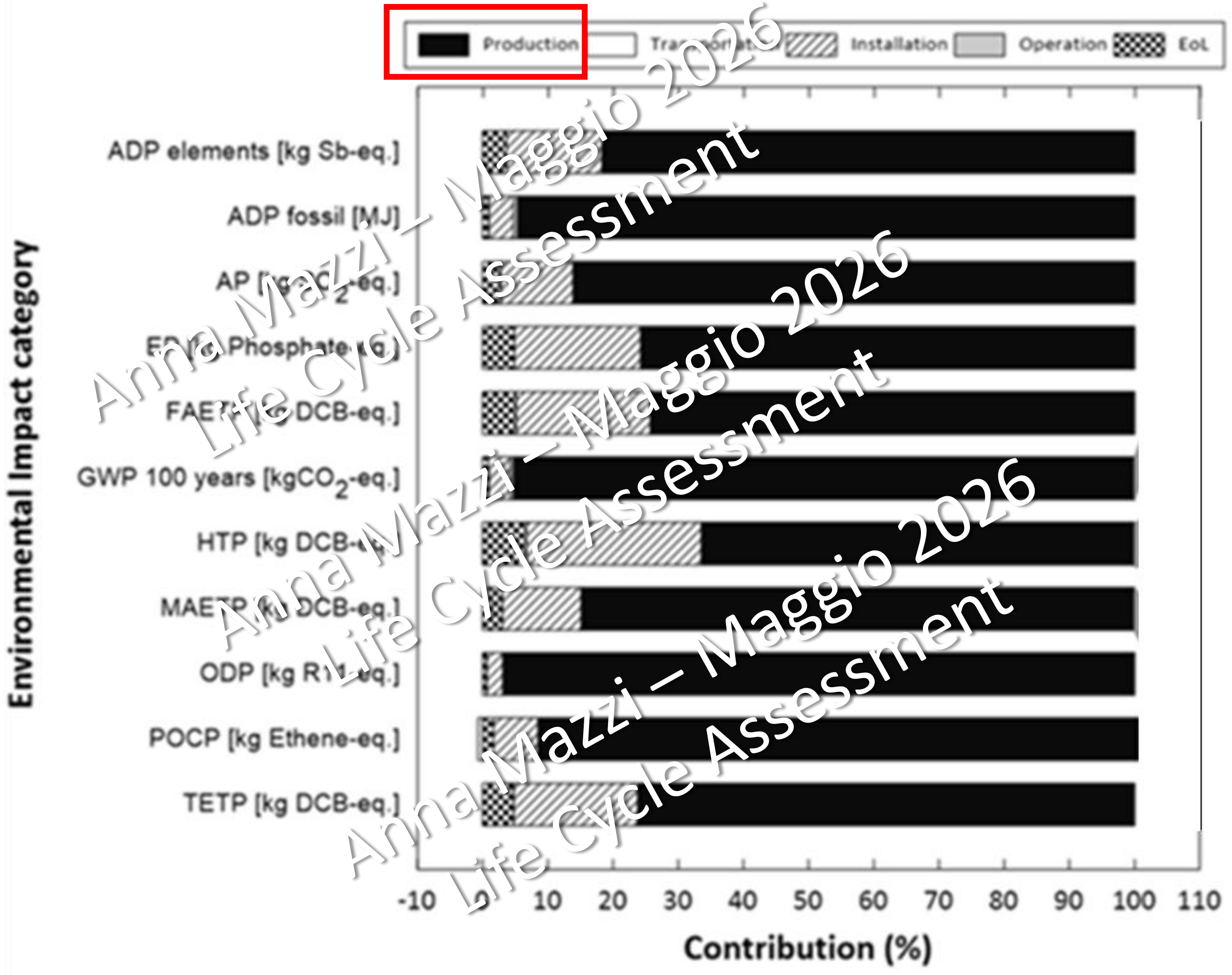
A first life cycle assessment study for the evaluation of a grid-connected photovoltaic system in Mexico was carried out from a cradle-to-grave perspective. The photovoltaic system consists of 12 modules integrated with a multi-crystalline silicon technology with a southward inclination of 20°, a 2.5 kW inverter, and a total installed capacity of 3 kWp, which provides an annual average production of 1282 kWh/kWp with a performance factor of 0.75. This system was installed in a building located in Mexico City. Potential environmental impacts from this photovoltaic system were analysed in eleven categories. The life cycle results show that this technology is within the cleaner energy sources with least environmental impacts throughout its life span. The major environmental impacts were attributed to the production stage, and more specifically to the manufacturing of materials for the solar modules (which include PV panels, solar cells, and wafers). The multi-crystalline silicon photovoltaic system evaluated in this study was also compared with three conventional photovoltaic generation systems based on different technologies (i.e., single-crystalline silicon, the amorphous silicon, and the copper-indium-selenium solar cells). From this life cycle assessment, it was found that the multi-crystalline silicon system almost systematically exhibits the lower environmental burdens in most of the impact categories (six out of the eleven), in comparison with other systems which present larger contributions of pollutants during their life span. Regarding to the carbon footprint, it was found that the photovoltaic technology with the lowest global warming potential was related to the multi-crystalline silicon system (47.156 g CO_2-eq./kWh), whereas the greatest contribution (69.1 g CO_2-eq./kWh) was attributed to the single-crystalline silicon system.

By considering these environmental sustainability results, a better technological deployment might be achieved which may help to accelerate, and drive a massive use of solar energy resources towards a clean, sustainable and diversified energy future. Finally, the importance of mapping circular economy opportunities during recycling and waste disposal of materials and the sustainability trade-offs of solar PV systems have been highlighted as crucial research areas and innovation opportunities for future LCA works.

Santoyo-Castelazo et al., 2021. LCA for a grid-connected multi-crystalline silicon photovoltaic system of 3 kWp: A case study for Mexico
https://doi.org/10.1016/j.jclepro.2021.128314

LCA per identificare le responsabilità ambientali





Santoyo-Castelazo et al., 2021. LCA for a grid-connected multi-crystalline silicon photovoltaic system of 3 kWp: A case study for Mexico
https://doi.org/10.1016/j.jclepro.2021.128314

LCA per identificare le responsabilità ambientali

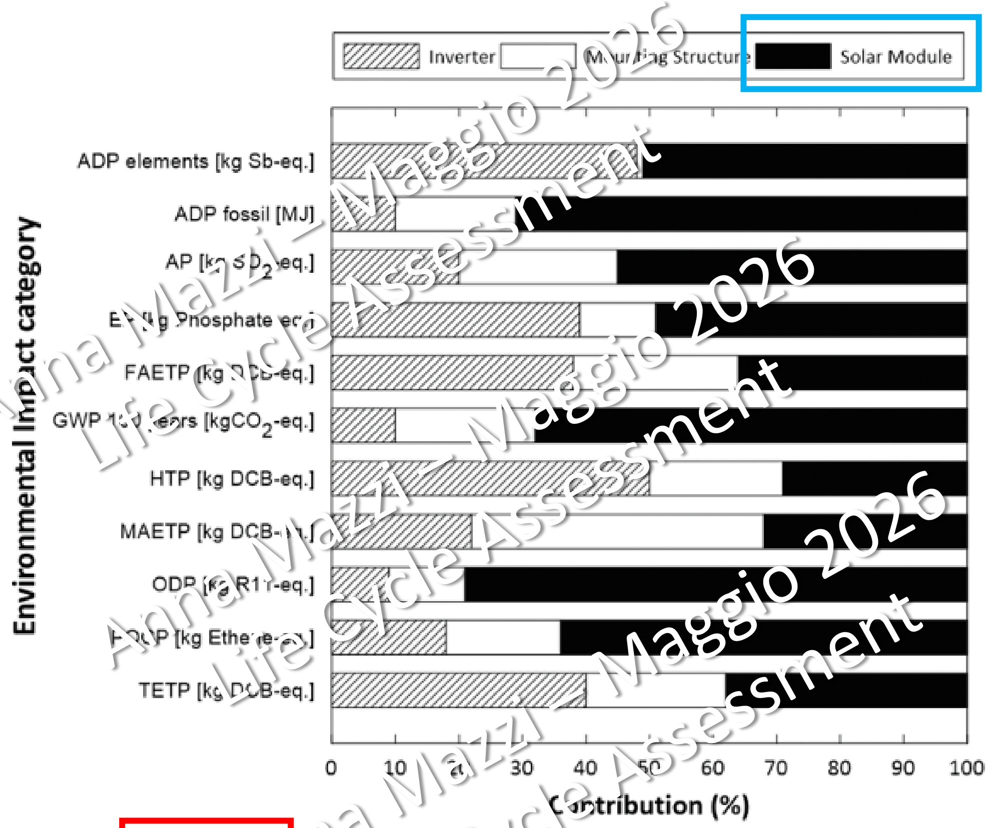


Fig. 7. Disaggregation of the production stage for evaluating the main environmental impacts of the solar mc-Si PV system (SoPVS-CDMX).

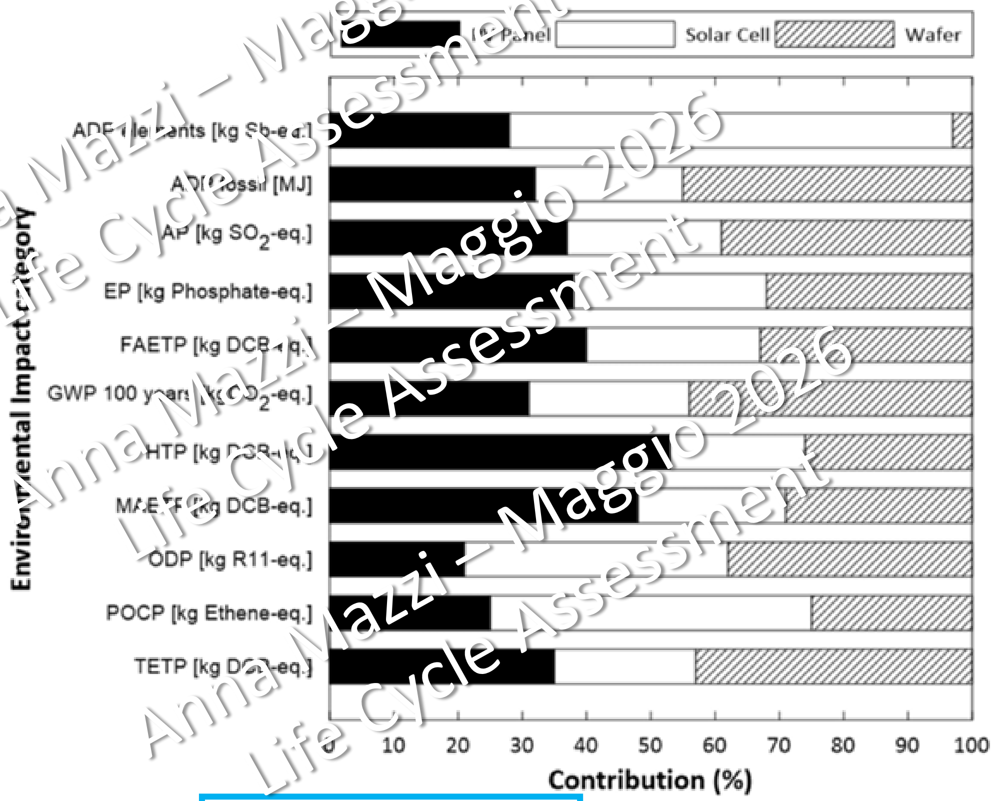


Fig. 8. Disaggregation of the manufacturing of the solar PV modules for evaluating their potential environmental impacts.

Santoyo-Castelazo et al., 2021. LCA for a grid-connected multi-crystalline silicon photovoltaic system of 3 kWp: A case study for Mexico
https://doi.org/10.1016/j.jclepro.2021.128314

LCA a supporto dello sviluppo di nuovi materiali (Biopolymers)

Hottle et al., 2013. https://doi.org/10.1016/j.polymdegradstab.2013.06.016
Sustainability assessments of bio-based polymers

Polymer Degradation and Stability 98 (2013) 1898–1907

Contents lists available at SciVerse ScienceDirect

Polymer Degradation and Stability

journal homepage: www.elsevier.com/locate/polydegstab

ELSEVIER

Review article

Sustainability assessments of bio-based polymers

A B S T R A C T

Bio-based polymers have become feasible alternatives to traditional petroleum-based plastics. However, the factors that influence the sustainability of bio-based polymers are often unclear. This paper reviews published life cycle assessments (LCAs) and commonly used LCA databases that quantify the environmental sustainability of bio-based polymers and summarizes the range of findings reported within the literature. LCA is discussed as a means for quantifying environmental impacts for a product from its cradle, or raw materials extraction, to the grave, or end of life. The results of LCAs from existing databases as well as peer-reviewed literature allow for the comparison of environmental impacts. This review compares standard database results for three bio-based polymers – polylactic acid (PLA), polyhydroxyalkanoate (PHA), and thermoplastic starch (TPS) with five common petroleum derived polymers. The literature showed that biopolymers, coming out of a relatively new industry, exhibit similar impacts compared to petroleum-based plastics. The studies reviewed herein focused mainly on global warming potential (GWP) and fossil resource depletion while largely ignoring other environmental impacts, some of which result in environmental tradeoffs. The studies reviewed also varied greatly in the scope of their assessment. Studies that included the end of life (EOL) reported much higher GWP results than those that limited the scope to resin or granule production. Including EOL in the LCA provides more comprehensive results for biopolymers, but simultaneously introduces greater amounts of uncertainty and variability. Little life-cycle data is available on the impacts of different manners of disposal, thus it will be critical for future sustainability assessments of biopolymers to include accurate end of life impacts.

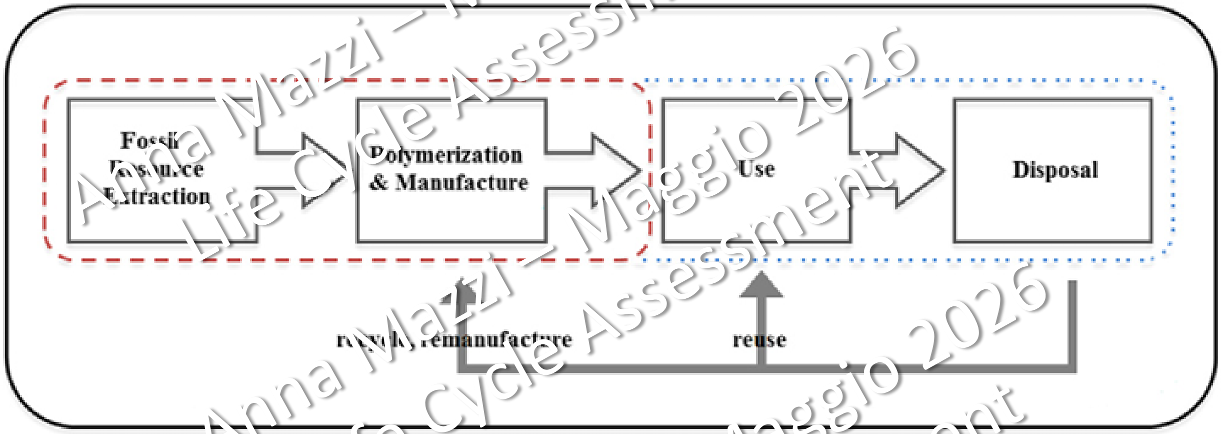
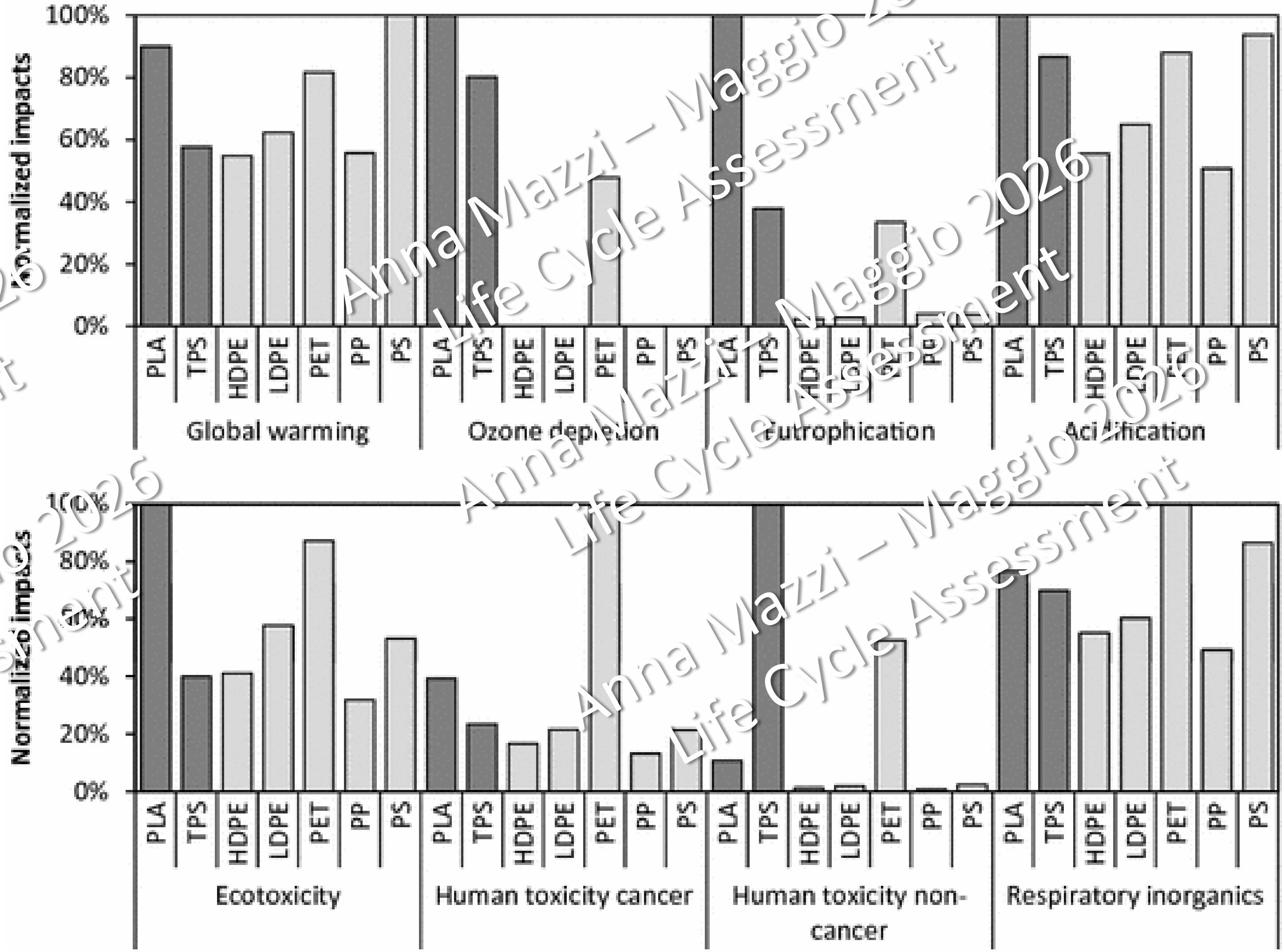


Fig. 1. Generic life-cycle stages for polymers. The dashed line indicates a cradle to gate system boundaries, the dotted line is an extension of that system boundary to cradle to grave, and the entire figure is indicative of a cradle to cradle assessment.

LCA a supporto dello sviluppo di nuovi materiali (Biopolymers)

Hottle et al., 2013. https://doi.org/10.1016/j.polymdegradstab.2013.06.016
Sustainability assessments of bio-based polymers

Higher impacts for bio-based polymers associated with
- feedstock-related agricultural emissions of fertilisers (eutrophication)
- pesticides (human toxicity and ecotoxicity)
- deforestation (impacts related to changes in land use)



LCA per confrontare la sostenibilità ambientale di tecnologie (PVs)

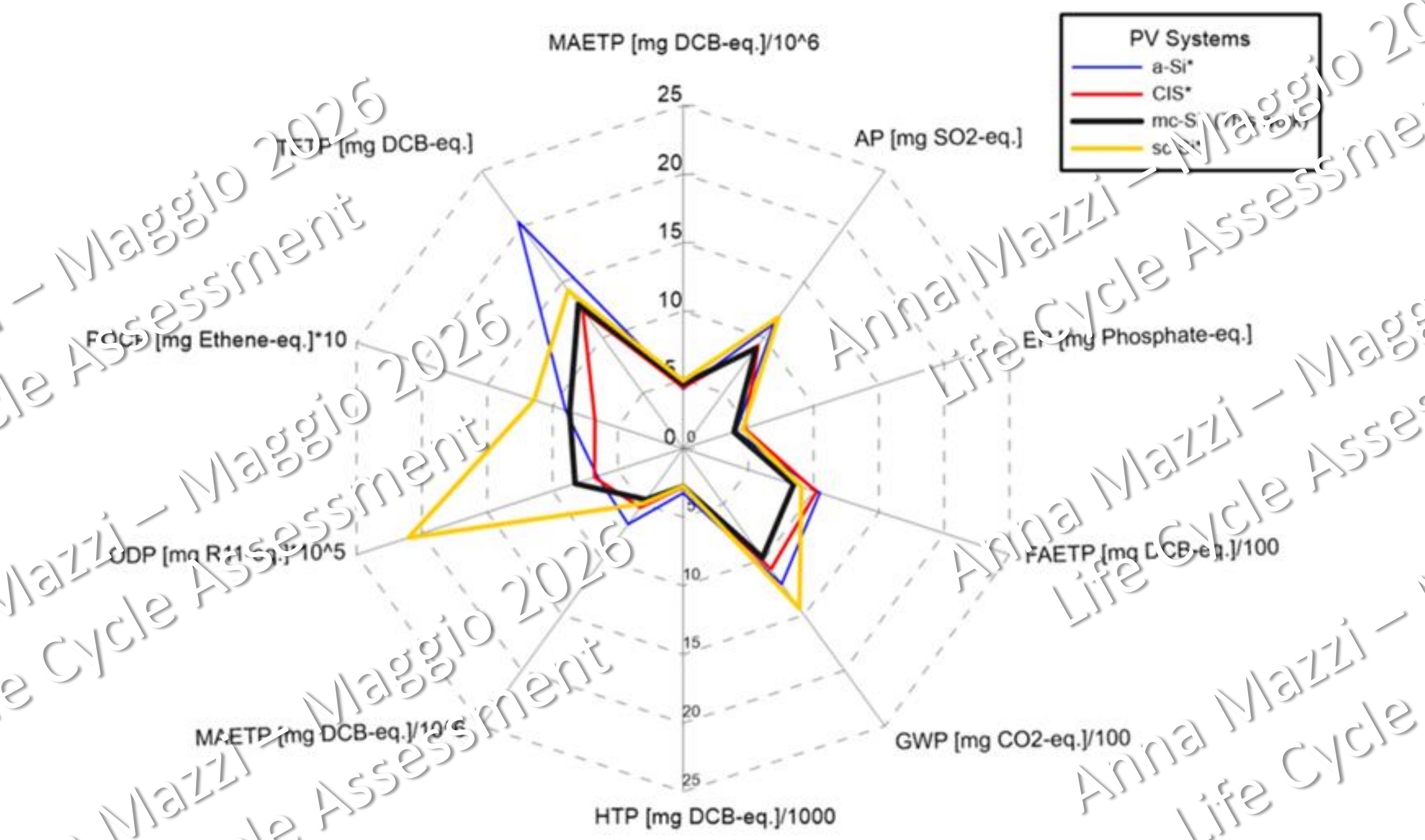
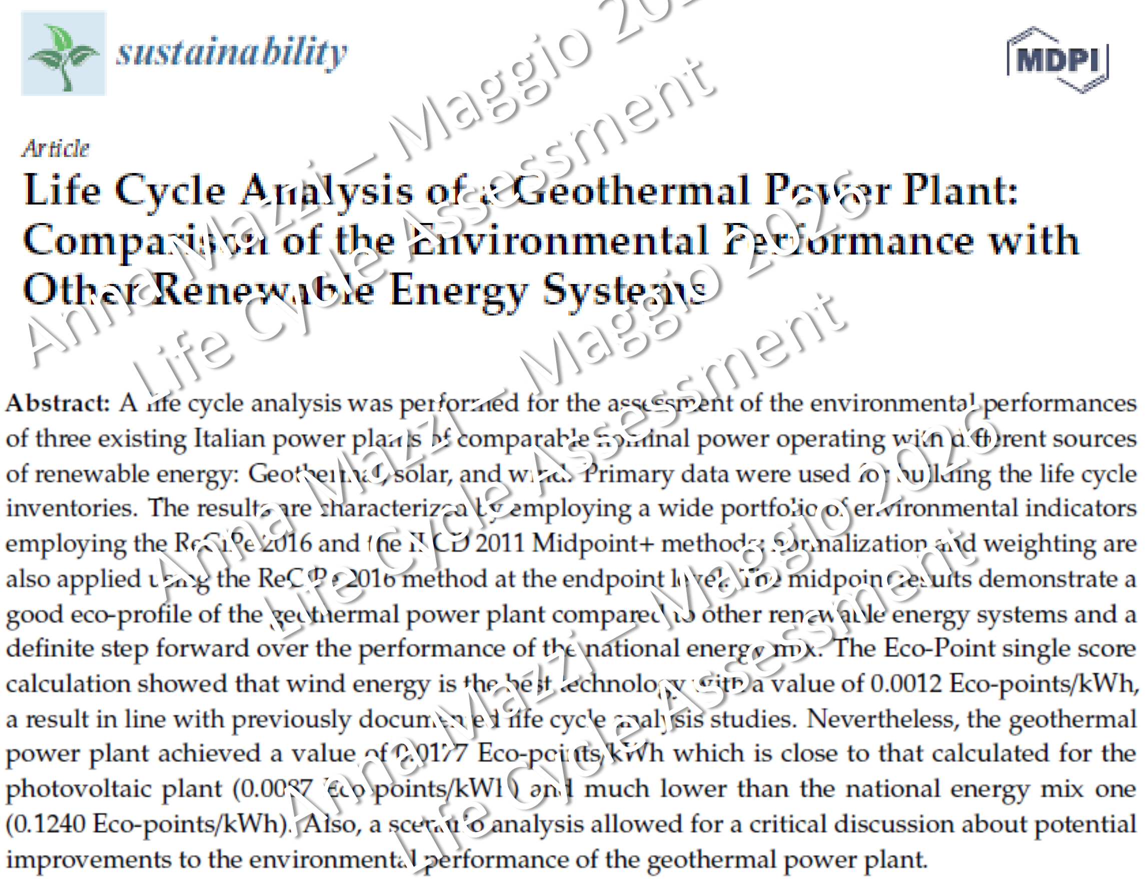


Fig. 5. Radar chart showing the comparison of the carbon footprint (GWP) and other ten environmental impact categories among the mc-Si PV system under evaluation (SoPVS-CDMX) and other solar PV technologies (a-Si, CIS, and sc-Si).

Santoyo-Castelazo et al., 2021. LCA for a grid-connected multi-crystalline silicon photovoltaic system of 3 kWp: A case study for Mexico
https://doi.org/10.1016/j.jclepro.2021.128314

LCA per la gestione ambientale strategica (sistemi energetici)

Basosi et al., 2020: https://www.mdpi.com/2071-1050/12/7/2786/htm
Life Cycle Analysis of a Geothermal Power Plant: Comparison of the Environmental Performance with Other Renewable Energy Systems



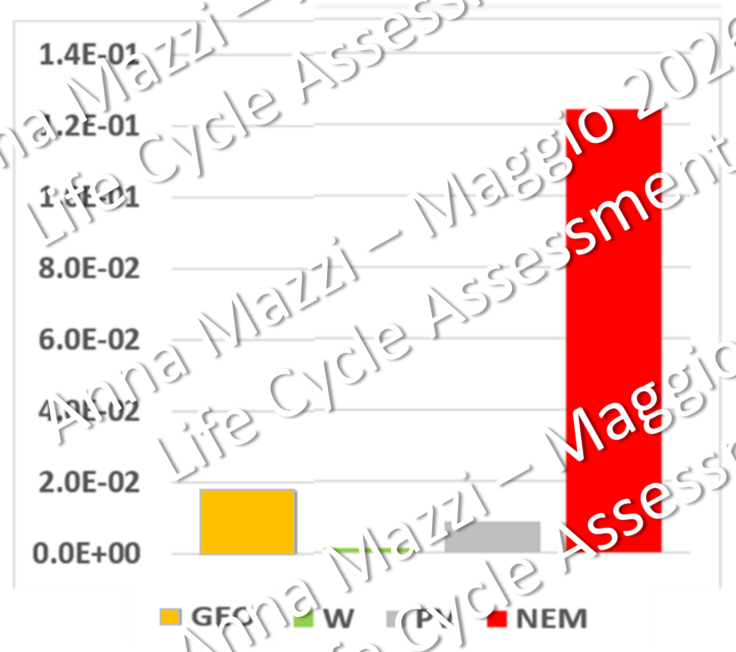
sustainability MDPI

Article

Life Cycle Analysis of a Geothermal Power Plant: Comparison of the Environmental Performance with Other Renewable Energy Systems

Abstract: A life cycle analysis was performed for the assessment of the environmental performances of three existing Italian power plants of comparable nominal power operating with different sources of renewable energy: Geothermal, solar, and wind. Primary data were used for building the life cycle inventories. The results are characterized by employing a wide portfolio of environmental indicators employing the ReCiPe 2016 and the ILCD 2011 Midpoint+ methods. Normalization and weighting are also applied using the ReCiPe 2016 method at the endpoint level. The midpoint results demonstrate a good eco-profile of the geothermal power plant compared to other renewable energy systems and a definite step forward over the performance of the national energy mix. The Eco-Point single score calculation showed that wind energy is the best technology with a value of 0.0012 Eco-points/kWh, a result in line with previously documented life cycle analysis studies. Nevertheless, the geothermal power plant achieved a value of 0.0177 Eco-points/kWh which is close to that calculated for the photovoltaic plant (0.0087 Eco-points/kWh) and much lower than the national energy mix one (0.1240 Eco-points/kWh). Also, a scenario analysis allowed for a critical discussion about potential improvements to the environmental performance of the geothermal power plant.

Figure 14. Weighted results calculated with the ReCiPe 2016 method (Eco-points/kWh).



GEO: geothermal
W: wind
PV: solar photovoltaic
NEM: national electricity mix (Italian energy mix based on Eurostat data for the year 2014 - renewable energies: 43.1%; coal: 19.0%; natural gas: 28.9%; oil: 1.0%; nuclear-imported: 4.6%; other sources: 3.7%)

LCA per confrontare alternative (sistemi energetici)

Basosi et al., 2020: https://www.mdpi.com/2071-1050/12/7/2786/htm

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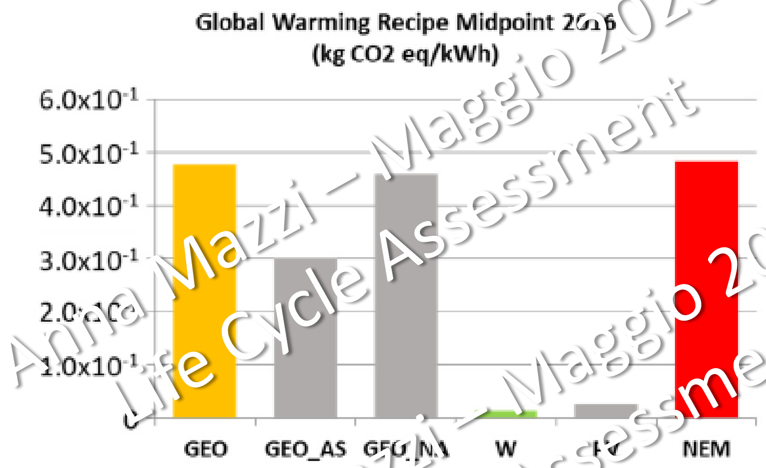
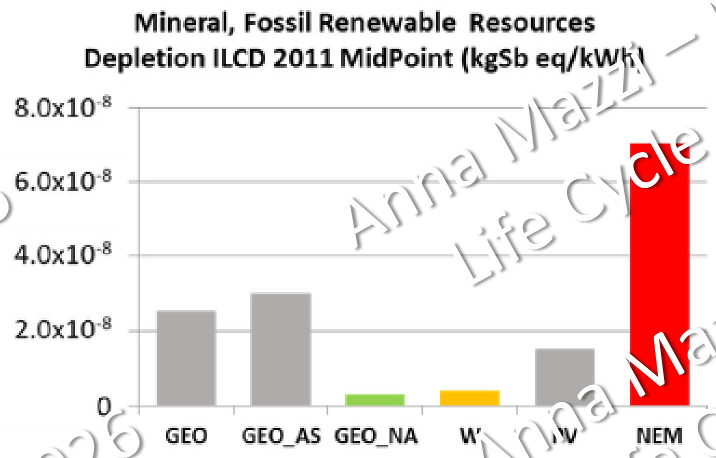
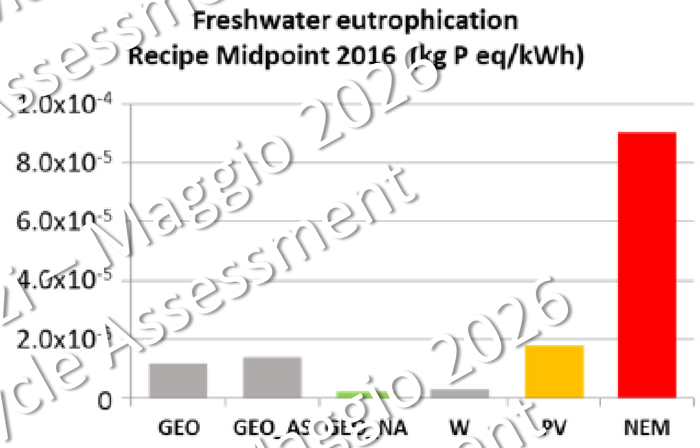
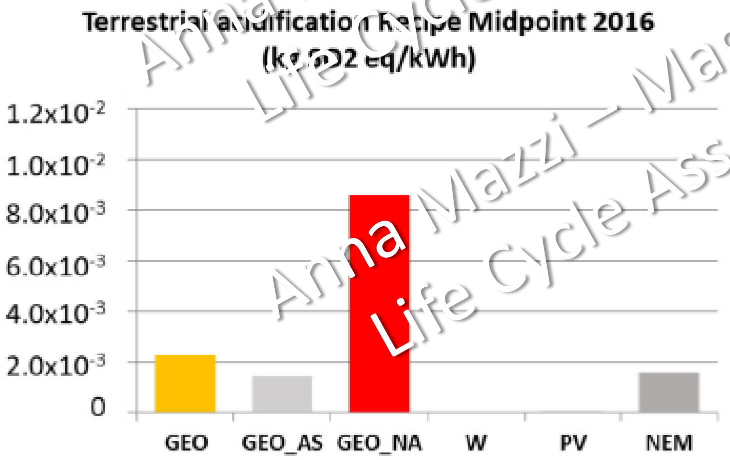
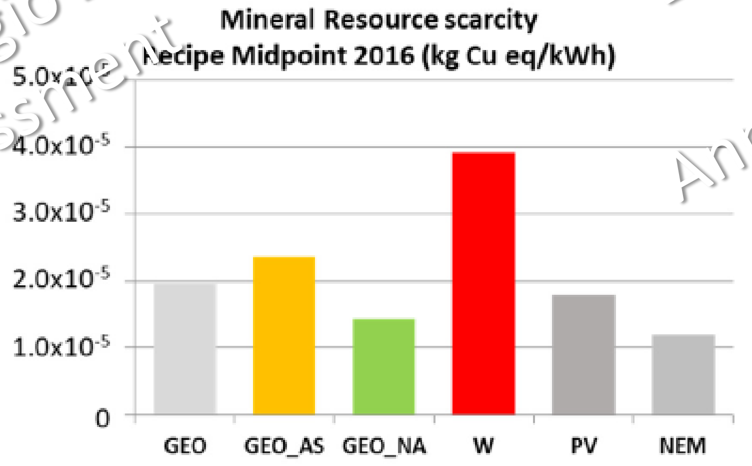
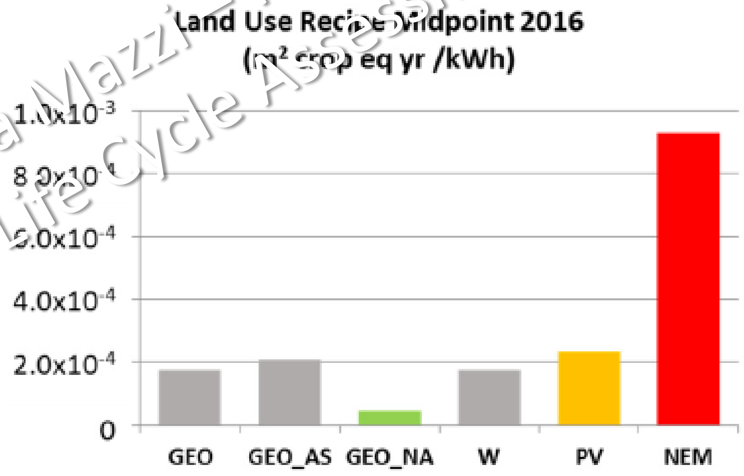










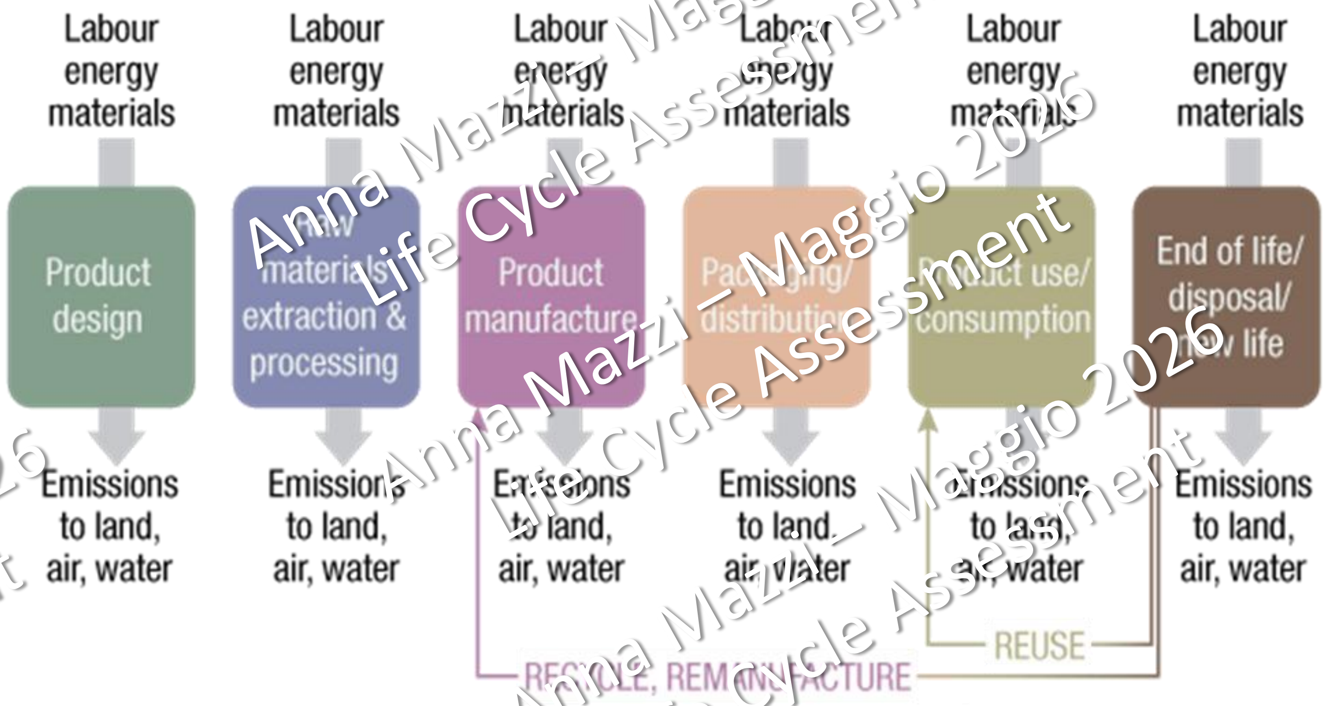


Perché LCA è tanto richiesto?

https://www.lifecycleinitiative.org/activities/what-is-life-cycle-thinking/

Life Cycle Initiative
hosted by UN environment programme

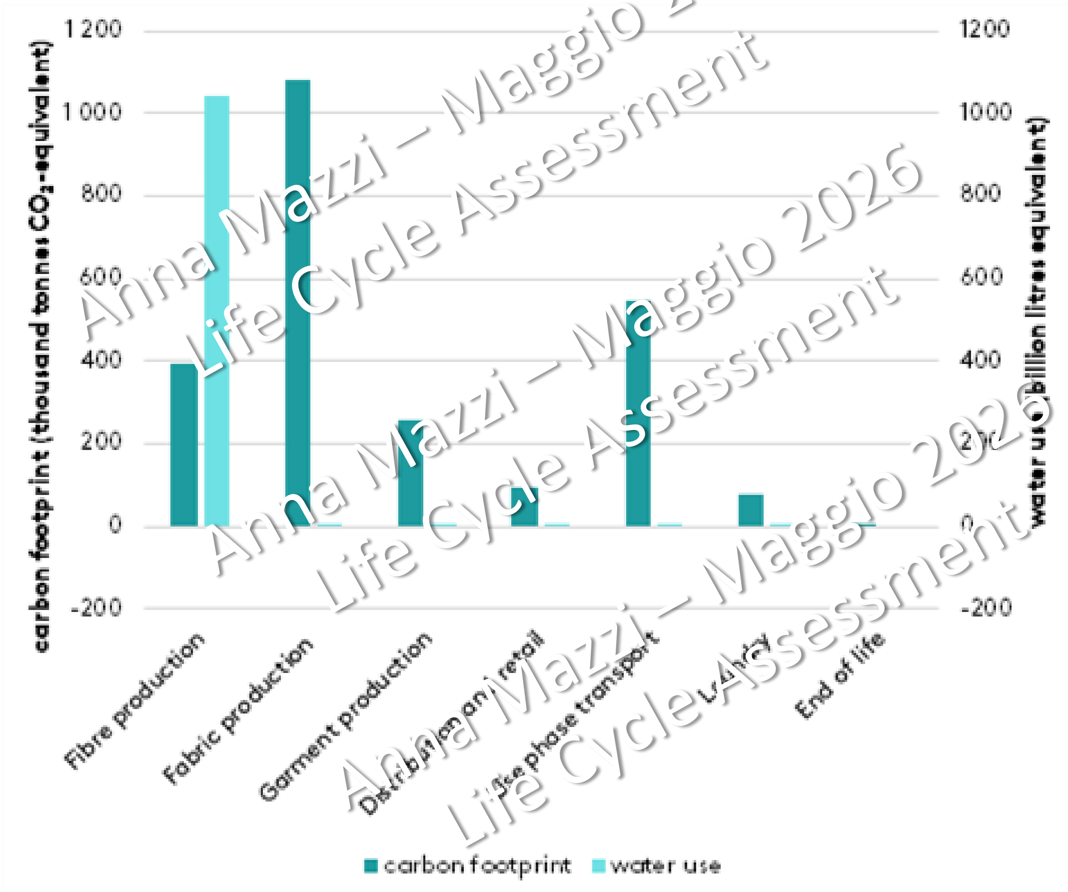
“In each life cycle stage there is the potential to reduce resource consumption and improve the performance of products”



Life Cycle approach: to quantify environmental + economic + social effects from input-output balance

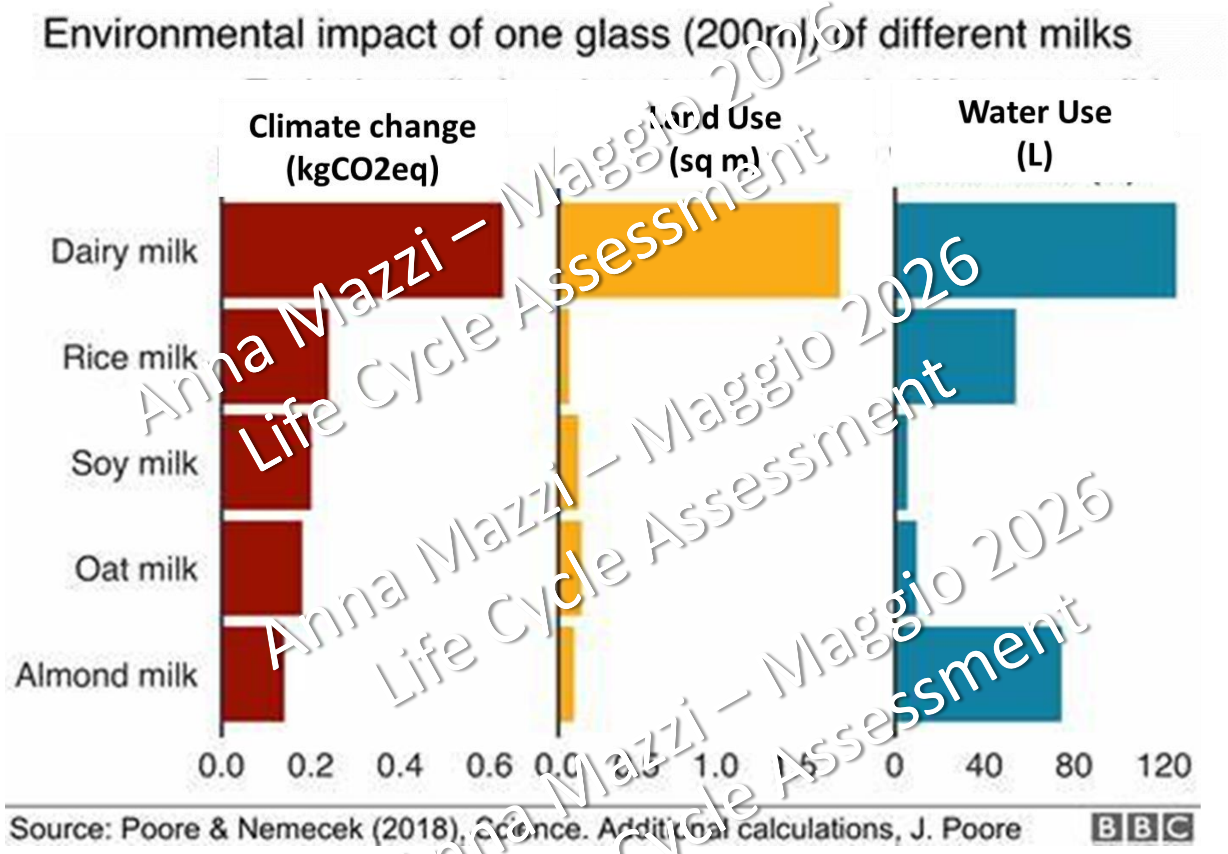
8 DECENT WORK AND ECONOMIC GROWTH
12 RESPONSIBLE CONSUMPTION AND PRODUCTION

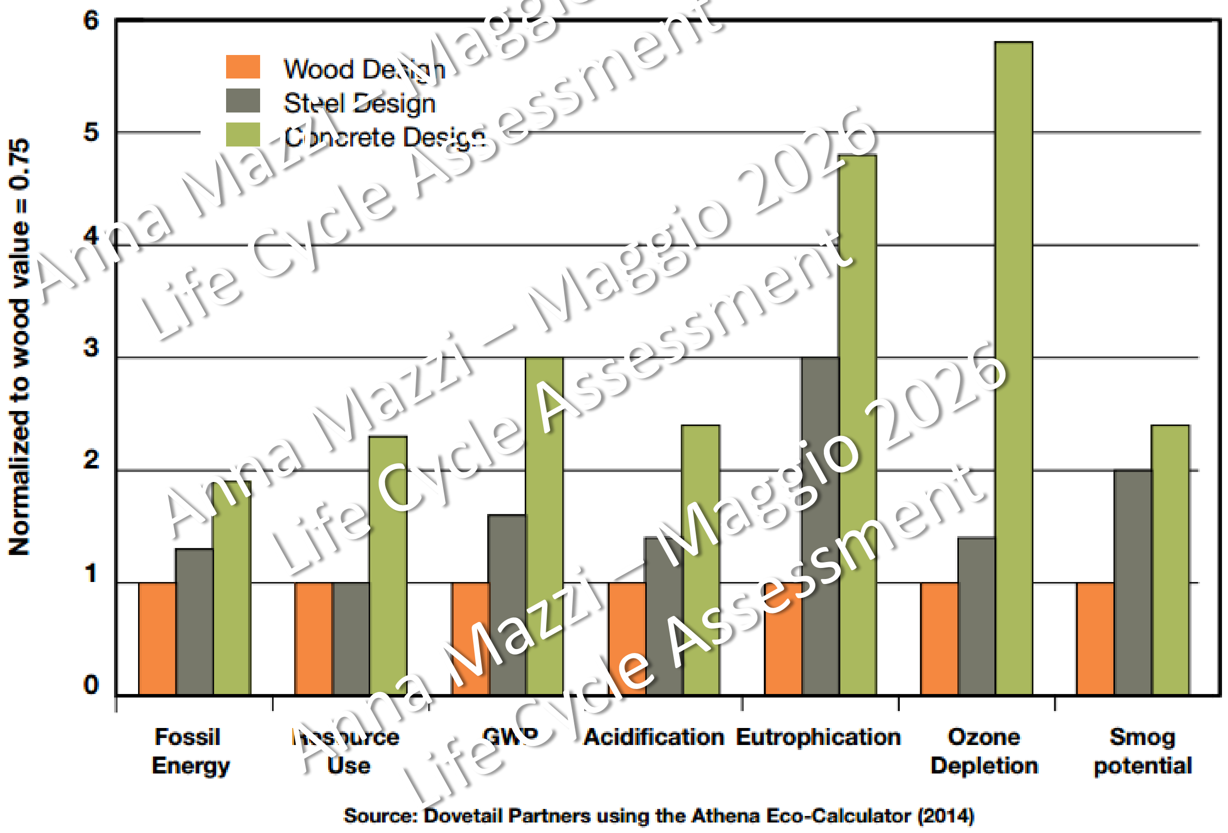
Vantaggi dall'utilizzo di LCA
Valutazioni «comprehensive»



http://mistrafuturefashion.com/wp-content/uploads/2015/06/Environmental-assessment-of-Swedish-fashion-consumption-LCA.pdf

Vantaggi dall'utilizzo di LCA
Confronto tra diverse alternative





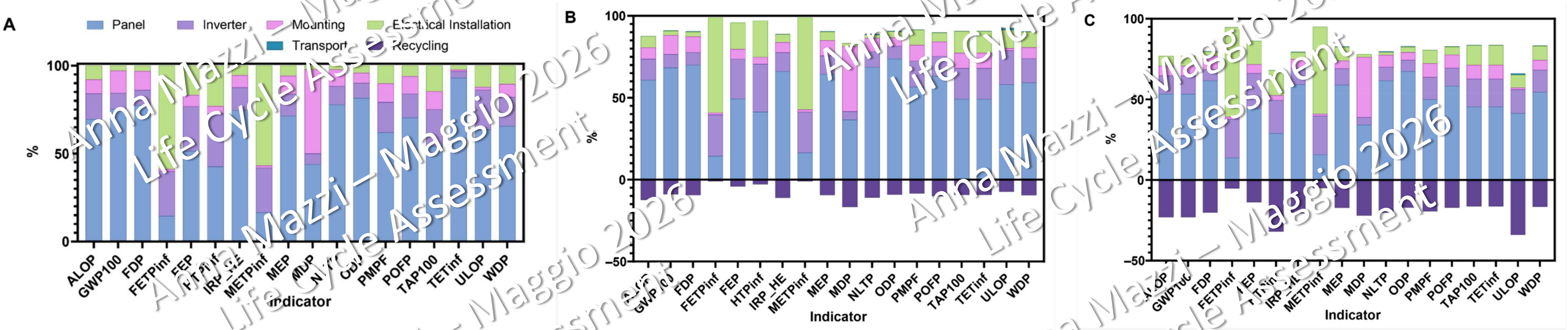
Vantaggi dall'utilizzo di LCA
Supportare le decisioni strategiche

Comparative LCA related to 3 EoL scenarios of PV panels: impact assessment results

Scenario A) Landfilling

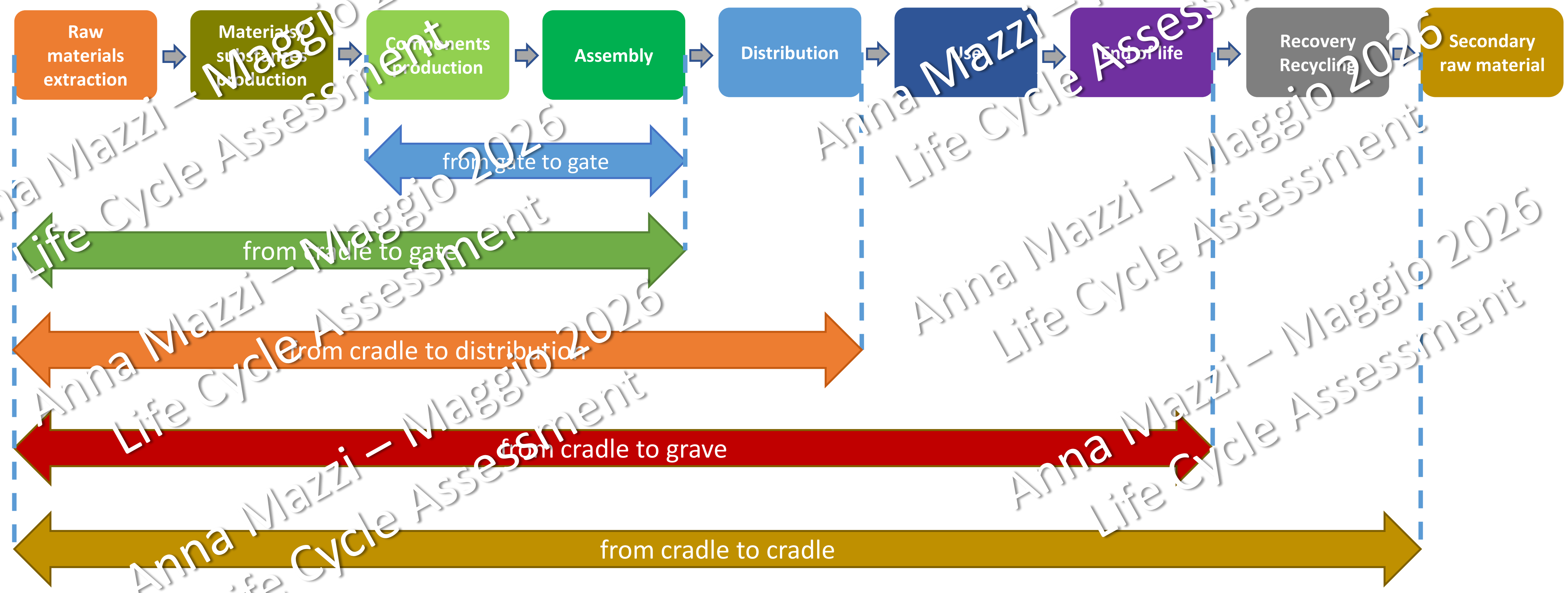
Scenario B) Low recycling (glass)

Scenario C) High recycling (multimaterials)

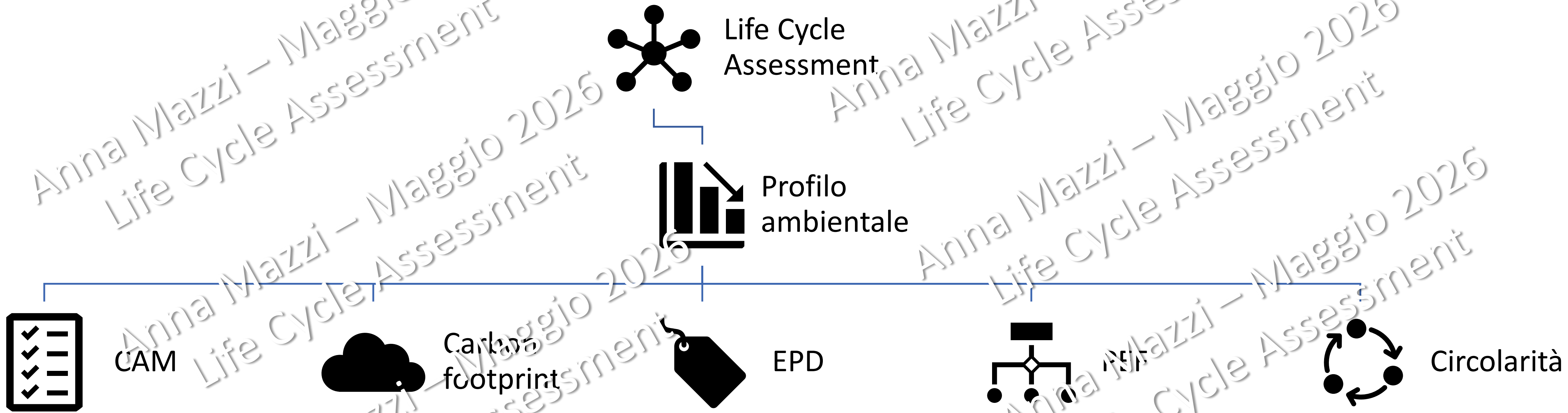


Singh et al., 2021. LCA of Disposed and Recycled End-of-Life PV Panels in Australia
https://doi.org/10.3390/su131911025

Vantaggi dall'utilizzo di LCA
Tante possibili applicazioni (livello di analisi)



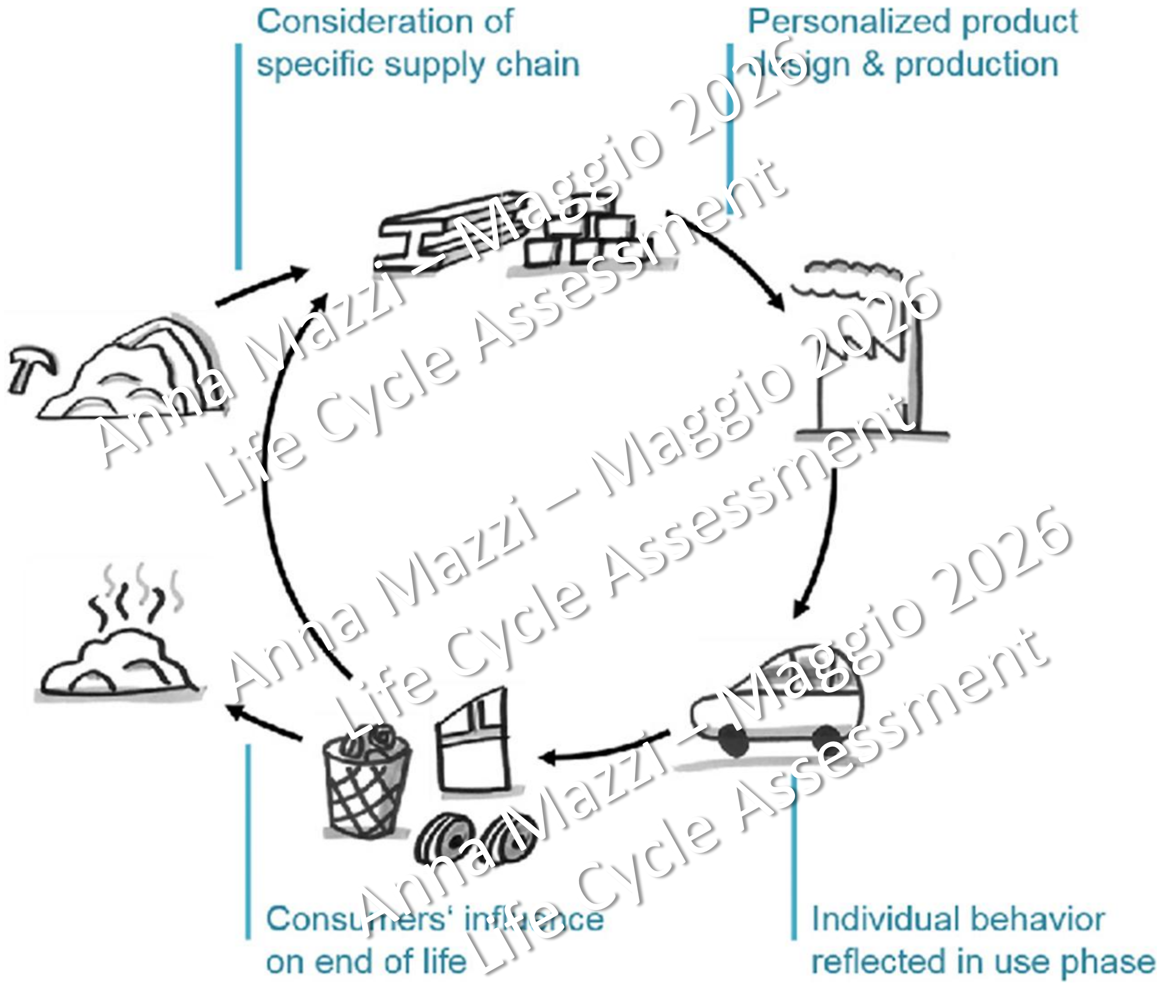
Vantaggi dall'utilizzo di LCA
Promuovere il green marketing



Criticità di LCA: «go out»

➡ Life cycle approach: prospettiva rivoluzionaria

Criticità di LCA: requisiti VS ipotesi



Risultati di LCA fortemente condizionati dalle ipotesi dello studio LCA

Criticità di LCA: inventory & impact assessment

No	Database	Region	Organization	Free or not	Da ty
1	Athena	Canada/ US	Athena Sustainable Materials Institute	License	Pro bas
2	Base Carbone	France	ADEME agency	Free	Pro bas
3	BEDEC	Spain	Institute of Technology of Construction	Free	Pro bas
4	BEES	US	US National Institute of Standards and Technology (NIST)	Free	Pro bas
5	CLCD	China	Sichuan University	Free	Pro bas
6	Ecoinvent	Switzerland	Swiss Centre for Life Cycle Inventories	License	Pro bas
7	Eco-Profiles	Europe	Plastics Europe	Free	Pro bas
8	ETH-ESU 96	Switzerland	Environmental Consultancy for Business and Authorities	Free	Pro bas
9	ELCD	Europe	European Commission	Free	Pro bas
10	GaBi	Germany	PE International	License	Pro bas
11	ICE	UK	Sustainable Energy Research Team of the University of Bath	Free	Pro bas
12	IDEMAT 2001	Netherlands	Delft University of Technology	Free	Pro bas
13	LCAiT	Sweden	Swedish Life Cycle Center	Free	Pro bas
14	ProBas	Germany	Federal Environment Agency	Limited	Pro bas
15	Synergia	Finland	Finnish Institute of Environment	Free	Pro bas
16	EIO-LCA	US	Carnegie Mellon University	Free	I-O
17	US Life Cycle Inventory	US	National Renewable Energy Laboratory (NREL)	Free	I-O

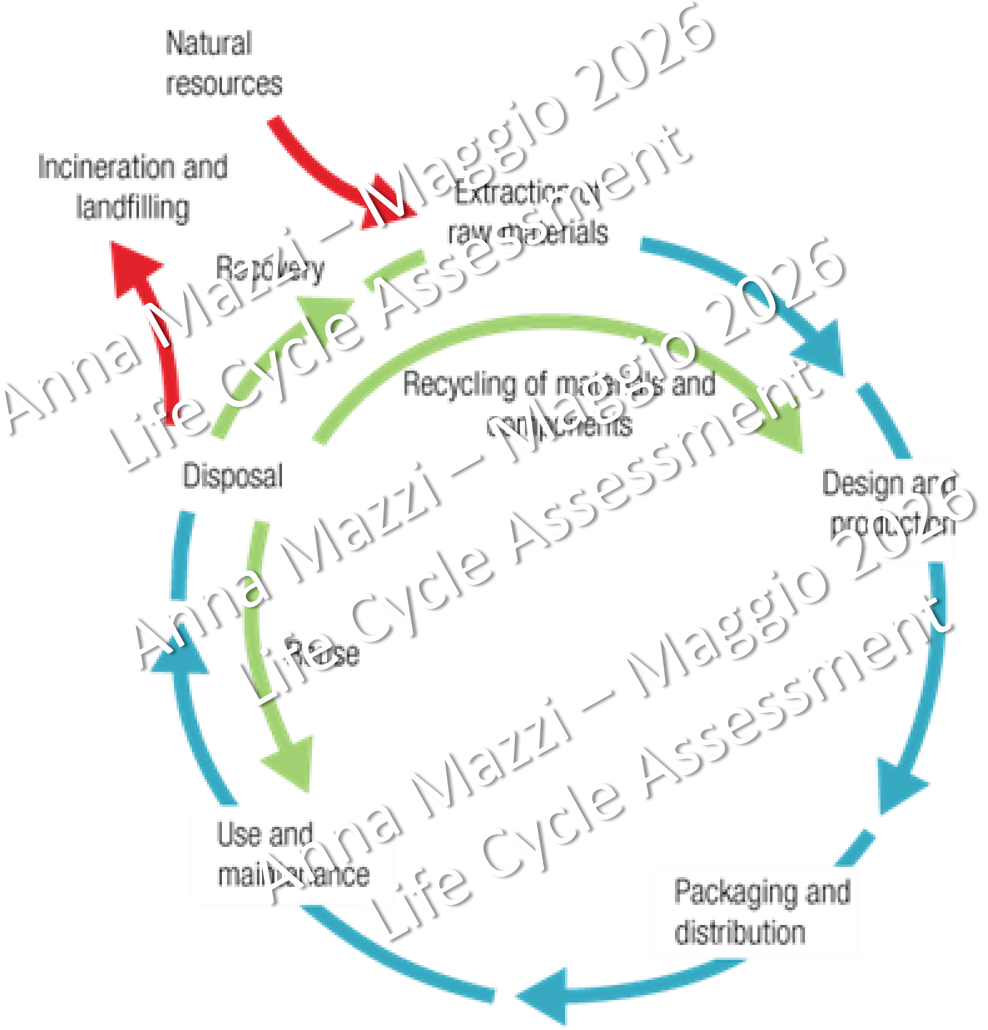
METHODS	Acidification	Climate change	Resource depletion	Ecotoxicity	Energy Use	Eutrophication	Human toxicity	Ionising Radiation	Land use	Odour	Ozone layer depletion	Particulate matter/ Respiratory inorganics	Photochemical oxidation
CML (baseline)	✓	✓	✓	✓	-	✓	✓	-	-	-	✓	-	✓
CML (non baseline)	✓	✓	✓	✓	-	✓	✓	✓	✓	✓	✓	-	✓
Cumulative Energy Demand	-	-	-	-	✓	-	-	-	-	-	-	-	-
eco-indicator 99 (E)	✓	✓	✓	✓	-	✓	✓	✓	✓	-	✓	✓	-
eco-indicator 99 (H)	✓	✓	✓	✓	-	✓	✓	✓	✓	-	✓	✓	-
eco-indicator 99 (I)	✓	✓	✓	✓	-	✓	✓	✓	✓	-	✓	✓	-
Eco-Scarcity 2006	-	-	✓	-	-	-	-	-	-	-	-	-	-
ILCD 2011, endpoint	✓	✓	-	-	-	✓	✓	✓	✓	-	✓	✓	✓
ILCD 2011, midpoint	✓	✓	✓	✓	-	✓	✓	✓	✓	-	✓	✓	✓
ReCiPe Endpoint (E)	✓	✓	✓	✓	-	✓	✓	✓	✓	-	✓	✓	✓
ReCiPe Endpoint (H)	✓	✓	✓	✓	-	✓	✓	✓	✓	-	✓	✓	✓
ReCiPe Endpoint (I)	✓	✓	✓	✓	-	✓	✓	✓	✓	-	✓	✓	✓
ReCiPe Midpoint (L)	✓	✓	✓	✓	-	✓	✓	✓	✓	-	✓	✓	✓
ReCiPe Midpoint (H)	✓	✓	✓	✓	-	✓	✓	✓	✓	-	✓	✓	✓
ReCiPe Midpoint (I)	✓	✓	✓	✓	-	✓	✓	✓	✓	-	✓	✓	✓
TRACI 2.1	✓	✓	✓	✓	-	✓	✓	-	-	-	✓	✓	✓
USEtox	-	-	-	✓	-	-	✓	-	-	-	-	-	-

Table 1: Availability of impact categories per method. ✓ represents that the impact category is contained in the correspondent method and - that not.

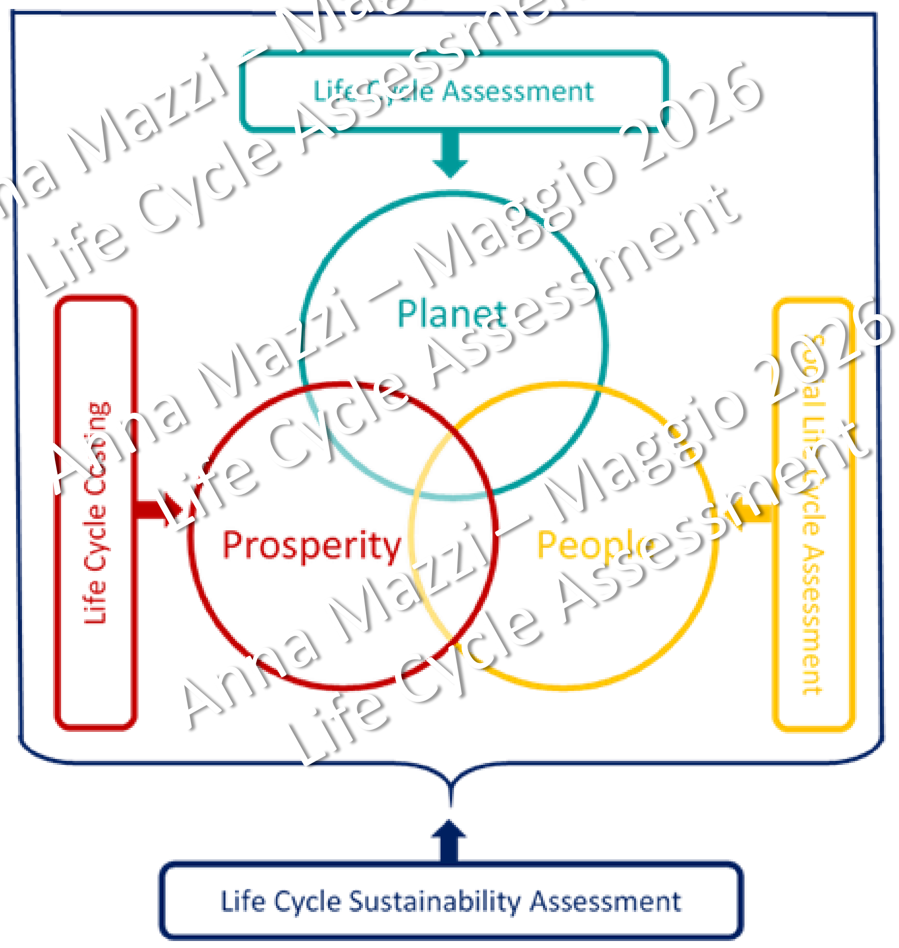
➡ **Datasets aggiornati, metodi di valutazione opportuni, software complessi**

Life Cycle Thinking: prospettive di sviluppo

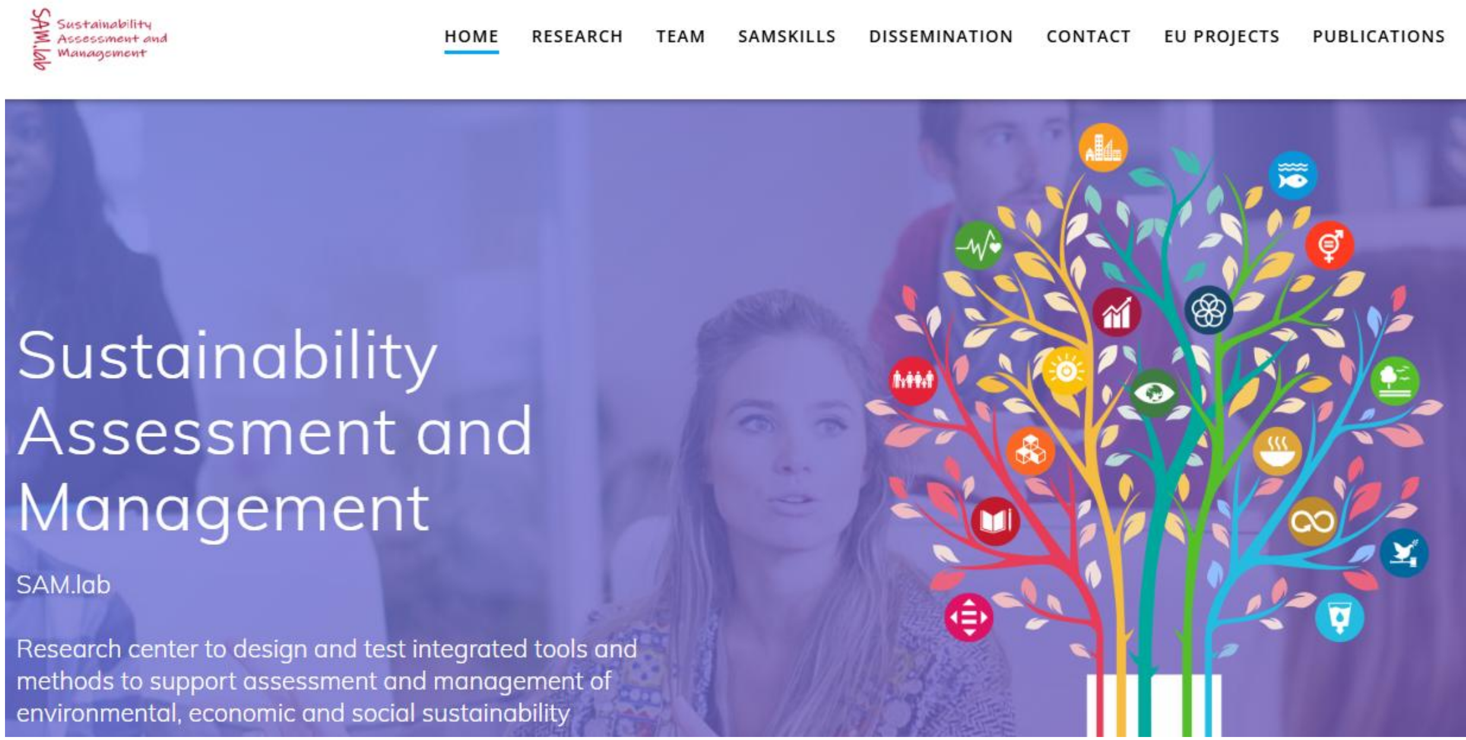
LCA to support Circular Economy



LCA to support Sustainable Development



Grazie per l'attenzione!!



https://research.dii.unipd.it/sam/

Per ulteriori informazioni o curiosità resto a disposizione
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