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MULTIDIMENSIONAL SUSTAINABILITY ASSESSMENT OF CIRCULAR ORANGE PEEL WASTE MANAGEMENT ALTERNATIVES

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SPOKE 8 | WP 8.4 | TASK 8.4.2

This research is part of Spoke 8 on **Circular economy in agriculture through waste valorization and recycling**, specifically in Work Package 8.4 on **Evaluation and assessment of new circular technologies in agriculture** and Task 8.4.2 on **Multidimensional sustainability assessment of circular technologies in agriculture**.

CONTEXT

Research activities carried out by the **PoliTo** team investigate technological options for processing **orange peel waste (OPW) by-products**. The research originates from a case study in **Task 8.1.3**, a technology currently developed by **Krill Design** for the production of an orange-based biocomposite with a biopolymer matrix. This technology has been deeply analyzed using LCA and other assessment methods, and a number of alternative OPW management technologies have been identified for further evaluation and comparison.

MATERIALS & METHODS

Starting from this input case study, the research includes the following **three action lines.**

The research uses a holistic multi-level and multi-dimensional sustainability assessment (environmental, social, economic).

Holistic Diagnosis

including SWOT, gap analysis, and Stakeholder analysis, currently conducted for Krill Design, and to be conducted both at the scale of the region of the company from which OPW by-products originated, and at the scale of the other companies developing technologies for OPW management

Life Cycle Assessment

of OPW streams, currently developed for partner in Task 8.1.3 – together with a sustainability assessment of the biopolymer PHA used for biocomposite manufacturing by Krill Design – and to be developed for the other companies involved in the study

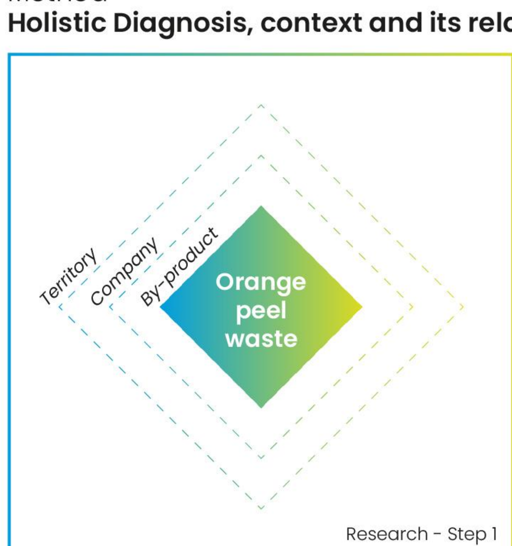
Multi-Criteria Decision Analysis

including the Analytic Hierarchy Process (AHP), already applied in a simulation comparing Krill Design with alternative technologies from the literature, and to be conducted with real case study alternative technologies, through Circular Economy indicators for the evaluation of OPW management innovative technologies

RESULTS & REFERENCES

Step 1

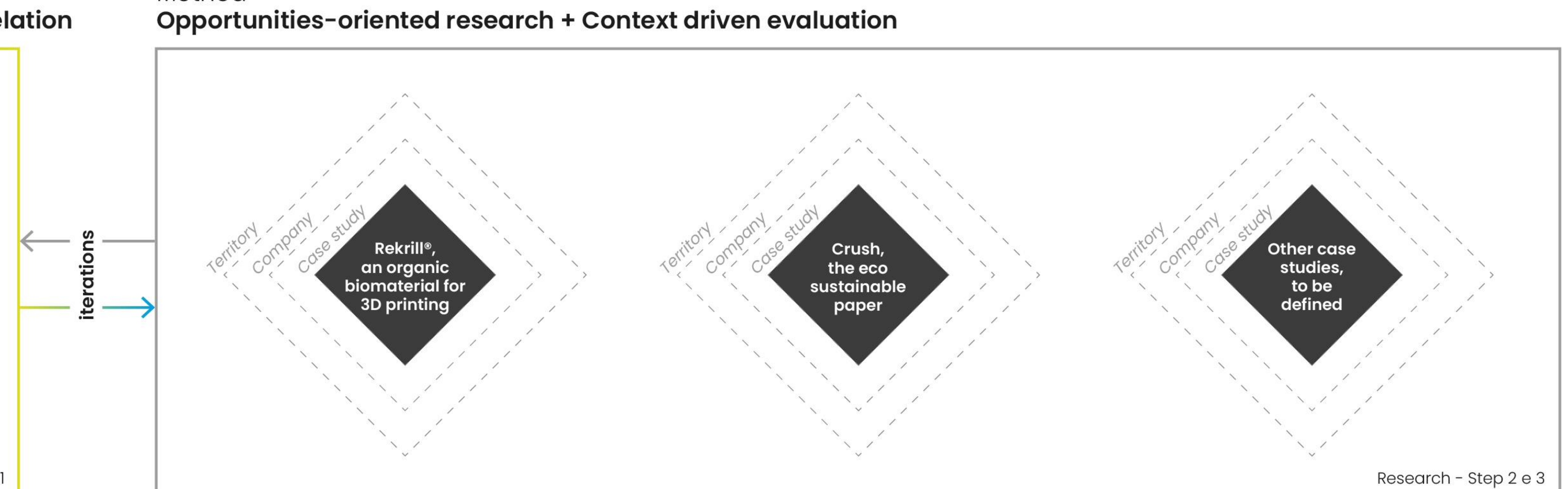
Method
Holistic Diagnosis, context and its relation



Analysis tool : Data collection tool

Output : Complexity map

Method
Opportunities-oriented research + Context driven evaluation



Analysis tool : Complexity map (Step 1) and Systemic matrix

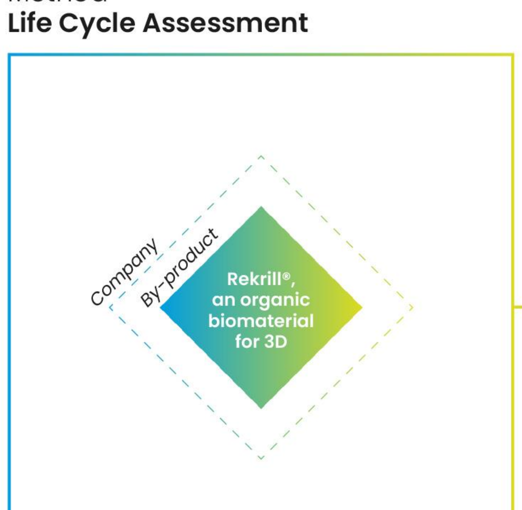
Output : Possible solution collection and Possible Systemic scenario

The first step focuses on the development of a **Holistic Diagnosis** (based on the Intent, Collection and Synthesis phases) (Battistoni et al., 2019). During the **Intent phase**, a customised research format (data collection tool) is created based on the research objectives and the characteristics of the context. In the **collection phase**, both quantitative and qualitative data are collected. In the **synthesis phase**, the data are then correlated to reveal connections and interdependencies, resulting in a visual representation known as a complexity map (output) that illustrates the context and origin of orange peel waste.

With the **complexity map (tool)** in the second stage, the research explores technological options for the valorisation of orange by-products through an opportunity-oriented approach (Sevaldson, 2011). This approach leads to the third stage: a contextual assessment of the identified opportunities, using the systemic matrix (tool). These two final stages aim to improve the understanding of how and when these opportunities can be effectively implemented within the analysed context, ultimately resulting in a set of potential solutions and a possible systemic scenario (output).

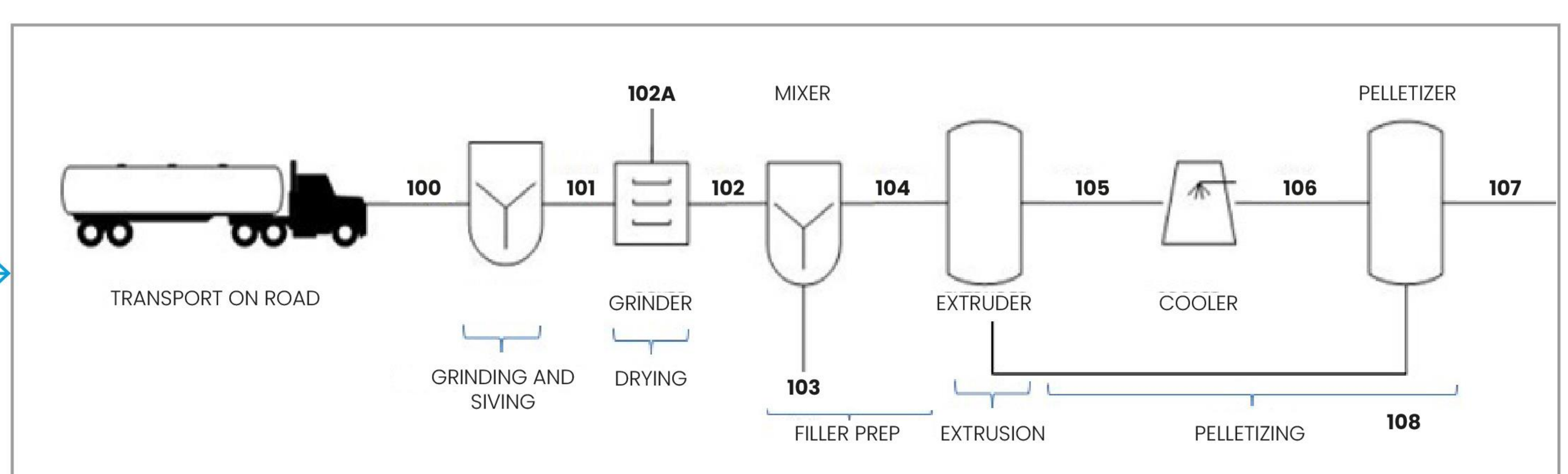
Step 2

Method
Life Cycle Assessment



Analysis tool : LCA

Output : OPW streams impacts



The LCA analysis was conducted by "cradle to gate" using SimaPro v. 9.5.0.2, with the Functional Unit of 30 kg h-1 of biocomposite products, in the form of pellettized (composed by 25% of dried orange waste and 75% of pure PHA).

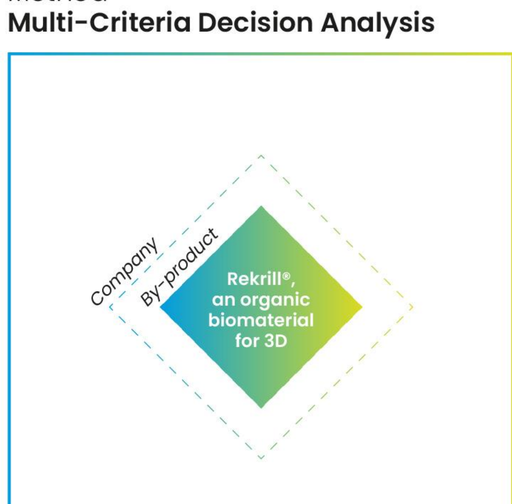
Next steps : Possible LCA application to other case studies, to be compared with Krill Design

The **LCA study** of the entire agro-waste chain aims to evaluate the environmental impacts associated with the entire lifecycle of the biocomposite, **from the sourcing of raw materials to the end-of-life disposal**. The orange waste-based composite is used to create different objects designed and produced by a start-up company, **Krill Design**. The integration of food waste, as orange-peel waste, with a biopolymers (e.g., PHA) to produce the waste-based composite aligns with the principles of a circular economy, where waste is minimized, and resources are continuously reused and recycled (Asunis et al., 2021; Tyagi et al., 2018; Kiselev et al., 2022; Korkakaki et al., 2016; Kuddus et al., 2020).

The LCA analysis was conducted from "cradle to gate" using SimaPro v. 9.5.0.2, with the Functional Unit of **30 kg h-1 of biocomposite products**, in the form of pelletized (composed by 25% of dried orange waste and 75% of pure PHA). The production of 30kg h-1 of bio-composite gives a **Warming Potential of 38.7 kg CO2** (38.7 kg CO2/FU, that corresponds to 1.29 kg CO2/kg pelletized). Through a comparison with fossil-based plastics, it results the least impactful. Similar analyses will be conducted on the other case studies in comparative terms.

Step 3

Method
Multi-Criteria Decision Analysis



Analysis tool : MCDA

Output : alternatives' ranking

Krill Design / Favini / *Others*	smarter product manufacture and use	R1	Rethink	Make product use more intensive (e.g. through sharing products or by putting multi-functional products on market).
		R2	Reduce	Increase efficiency in product manufacture or use by consuming fewer natural resources
	product lifespan extension	R7	Repurpose	Use discarded products or its part in a new product with a different function
Animal feed	product lifespan extension	R3	Reuse	Re-use by another consumer of discarded product which is still in good condition and fulfils its original function
Anaerobic digestion	useful application of materials	R8	Recycle	Process materials to obtain the same (high grade) or lower (low grade) quality
Pyrolisis	useful application of materials	R9	Recovery	Incineration of material with energy recovery

Next steps : conclusion of the survey and data collection on other case studies, to be compared with Krill Design

AHP, in combination with LCA, has been identified through literature review as the most widely used and promising. On the one hand, **techno-economic analyses** – related to LCA – allow comparison and environmental and technical analysis **between mature technologies** (e.g., pyrolysis, anaerobic digestion, animal feed) **and most recent technologies** (e.g., biomaterial production) and identification of the process that yields the lowest environmental impact for a given feedstock, on a larger scale. On the other hand, AHP allows a multi-dimensional analysis.

A preliminary collection of **Key Performance Indicators (KPIs)** has been derived from the literature and refined through experts' involvement. The KPIs were used in an internal simulation of AHP , comparing Krill Design with anaerobic digestion and animal feed alternatives from secondary data. Finally, further reviews have been conducted to identify **Circular Economy (CE)** indicators, through the literature and the **ISO 59020:2024**. The list of **27 indicators** has been refined using experts' survey, involving OPW management experts in Italy (ongoing). Once the KPIs are defined and measured, the AHP will allow to rank the alternative technologies of OPW management in a CE perspective (EMF, 2013; Potting et al., 2017; Kirchherr et al., 2017; Morseletto, 2020).

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