Environmental hotspots analysis of the second-generation polylactic acid (PLA) based on wheat straw

Ricardo Rebolledo-Leiva[1], Sofia-Maria Ioannidou [2], Ana Arias[1], Dimitris Ladakis[2], Apostolis Koutinas[2], María Teresa Moreira[1], Sara González-García[1]

[1] Department of Chemical Engineering, University of Santiago de Compostela, Spain
[2] Department of Food Science and Human Nutrition, Agricultural University of Athens, Iera Odos 75, 118 55 Athens, Greece

Introduction

Climate Change

Fossil depletion

Food security

End-of-life management of wheat straw:

Burned to reduce pests and weeds

Sold as feed or as bedding for livestock

Left in the field for soil amendment

Wheat is one of the most cultivated crop worldwide, playing a **key role in food security**

2 ZERO HUNGER

It is estimated that 354 Mt of wheat straw are generated annually in the world (Li & Chen, 2020).

Potential raw material to obtain added-value bio-products in a circular bioeconomy framework.

Biorefinery

Bio ≠ Eco

Li, S., Chen, G., 2020. Agricultural waste-derived superabsorbent hydrogels: Preparation, performance, and socioeconomic impacts. J. Clean. Prod. 251, 119669

Aim of study

Poly(lactic acid) (PLA)

One of the most representative biopolymers worldwide

460 **thousand tonnes produced in 2021[1]**

It could be used in textiles, packaging, disposable cutlery, 3D printing, and drug delivery

PLA is obtained from lactic acid (LA) using mainly starch feedstocks (1st generation feedstocks)

A major concern for bio-based products is the land use change required to meet the potentially growing demand.

Aim

Evaluate the environmental impacts of producing PLA from wheat straw and integrating a recycling strategy at early stage of design.

[1]European-bioplastics, 2022. https://www.european-bioplastics.org/market/#

Methodology framework

Wheat cultivation

Farm stage Inventory: Wheat straw

↓

Simulation of production process at Industrial scale

Mass and Energy balance

← **Lab data & Literature**

↓

Life Cycle Assessment

Environmental profile

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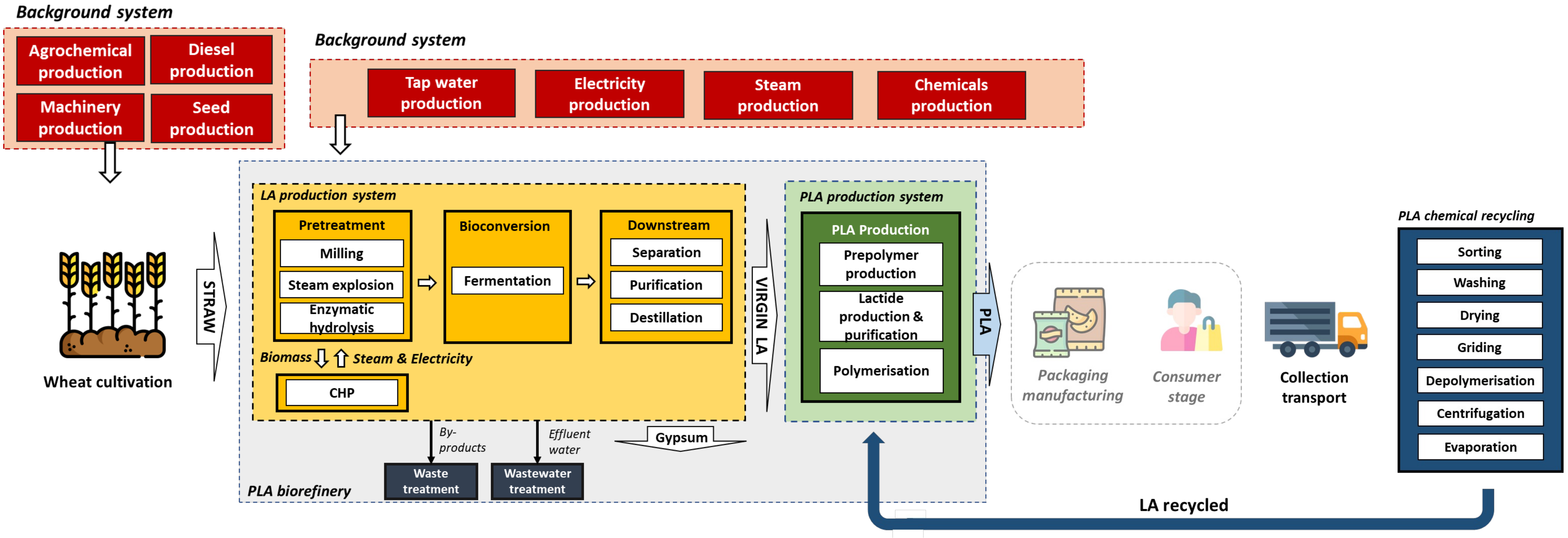
Interpretation and Scenarios Analysis

Improved environmental profile

System boundaries



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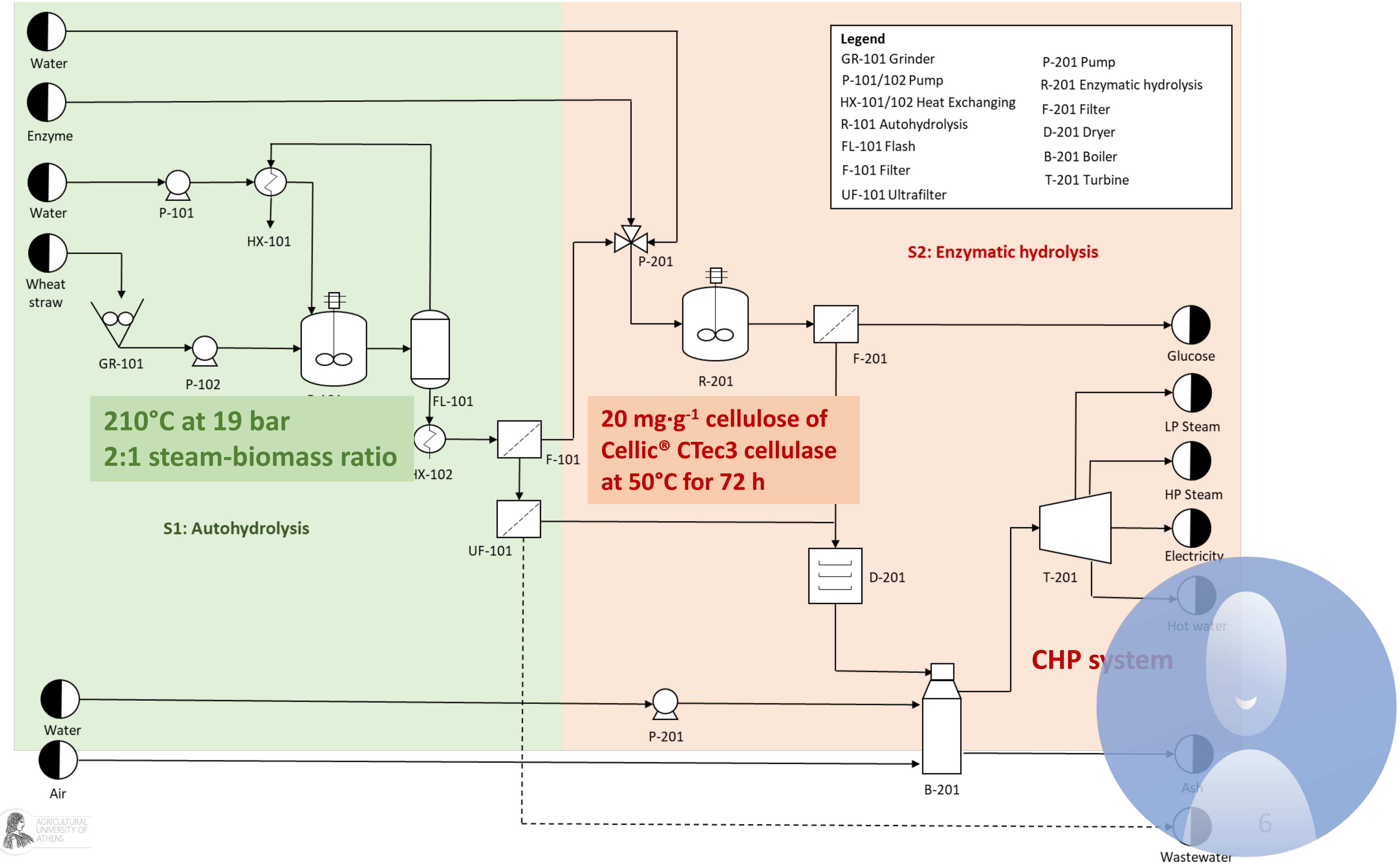
Pre-treatment of straw



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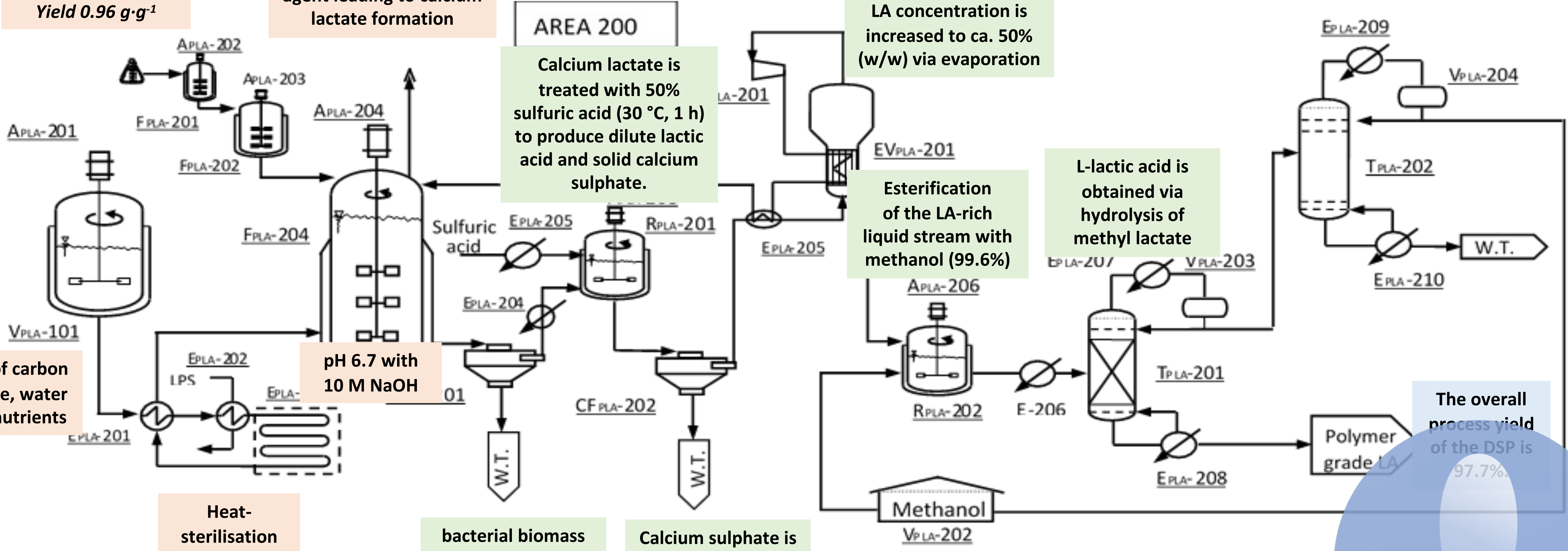
LA production system

Bioconversion

Bacillussp. 2-6
Yield 0.96 g·g⁻¹

Calcium carbonate is used in fermentation as a neutralizing agent leading to calcium lactate formation

Downstream (DSP)



Calcium lactate is treated with 50% sulfuric acid (30 °C, 1 h) to produce dilute lactic acid and solid calcium sulphate.

LA concentration is increased to ca. 50% (w/w) via evaporation

Esterification of the LA-rich liquid stream with methanol (99.6%)

L-lactic acid is obtained via hydrolysis of methyl lactate

Mix of carbon source, water and nutrients

pH 6.7 with 10 M NaOH

Heat-sterilisation

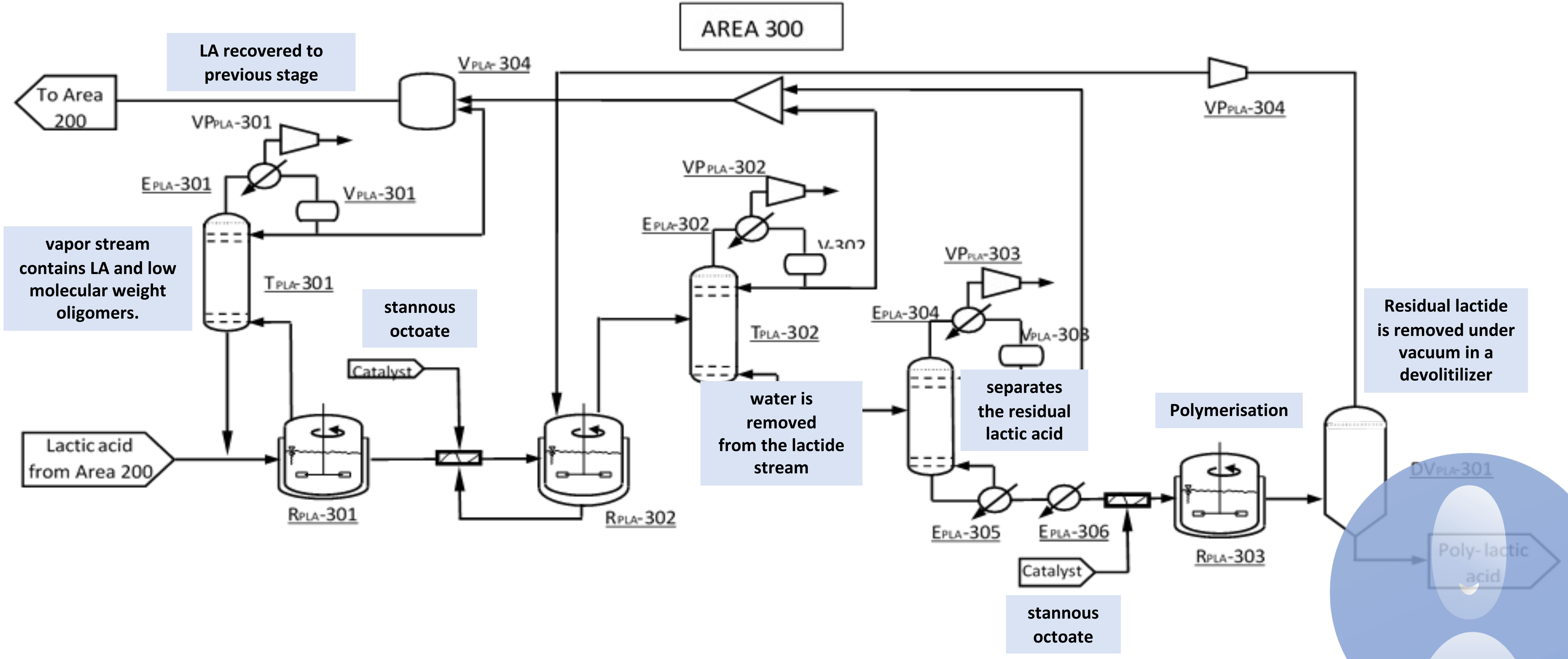
bacterial biomass separated from the fermentation broth via centrifugation

Calcium sulphate is separated from the product stream via centrifugation

The overall process yield of the DSP is 97.7%.

Ioannidou et al. (2022). Techno-economic risk assessment, life cycle analysis and life cycle costing for poly (butylene succinate) and poly (lactic acid) production using renewable resources. Science of The Total Environment, 806, 150594.

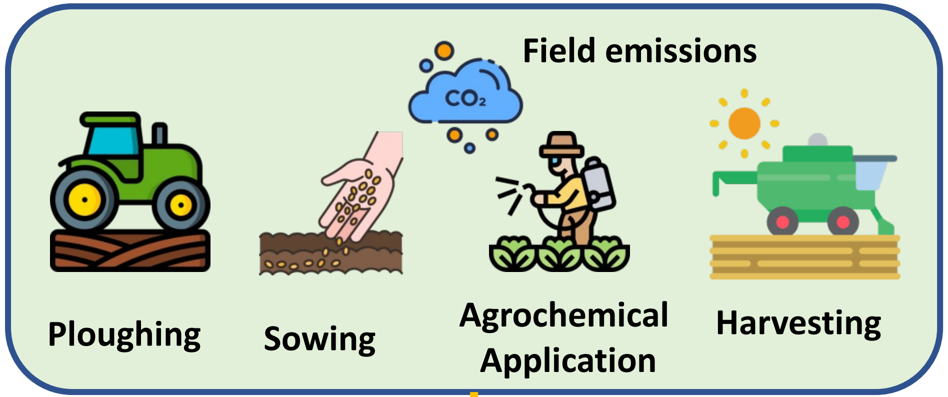
PLA production system



Ioannidou et al. (2022). Techno-economic risk assessment, life cycle analysis and life cycle costing for poly (butylene succinate) and poly (lactic acid) production using renewable resources. Science of The Total Environment, 806, 150594.

Life Cycle Inventory

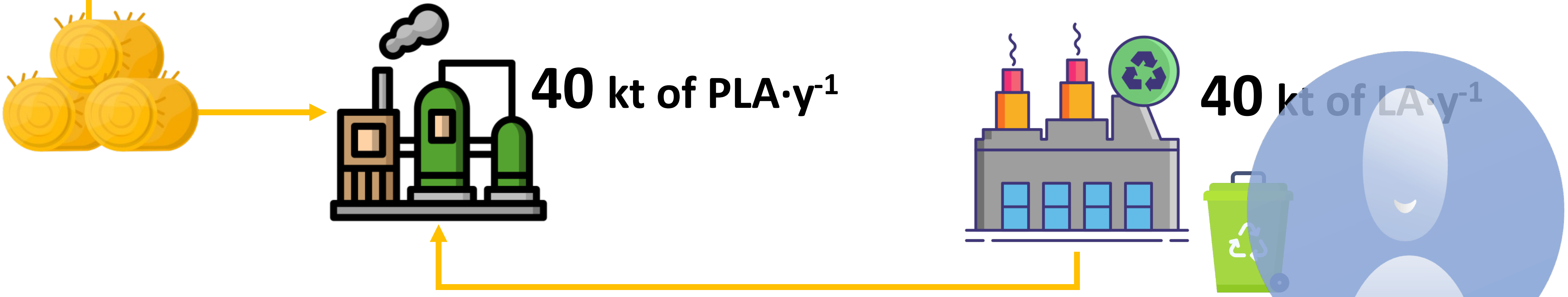
Farm stage



- Monoculture regimen of durum wheat
- Inventory data from Apulia, Italy
- Economic allocation (grain: 85% and straw: 15%)

0.29€·kg^{-1} **0.07€·kg^{-1}**

Biorefinery stage



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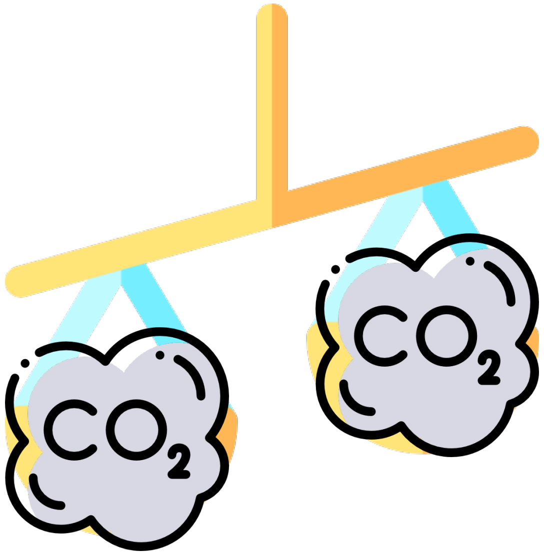
Environmental profile

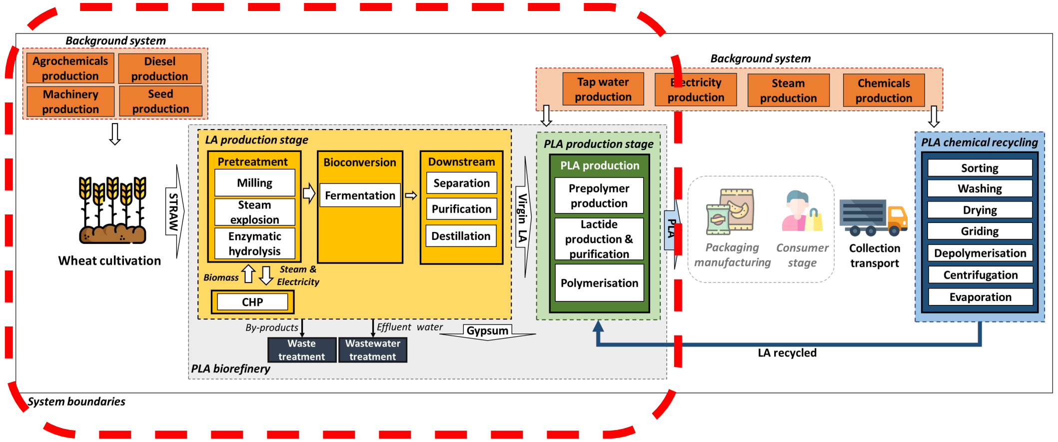
Environmental profile of 1 kg of straw-based PLA

Impact category	Unit	Total
GWP	kg CO_2 eq	**1.42**
PM	g PM2.5 eq	5.37
FE	g P eq	0.90
ME	g N eq	1.71
HT	g 1,4-DCB	0.07
LU	m^2a crop eq	0.53
FRS	kg oil eq	0.41

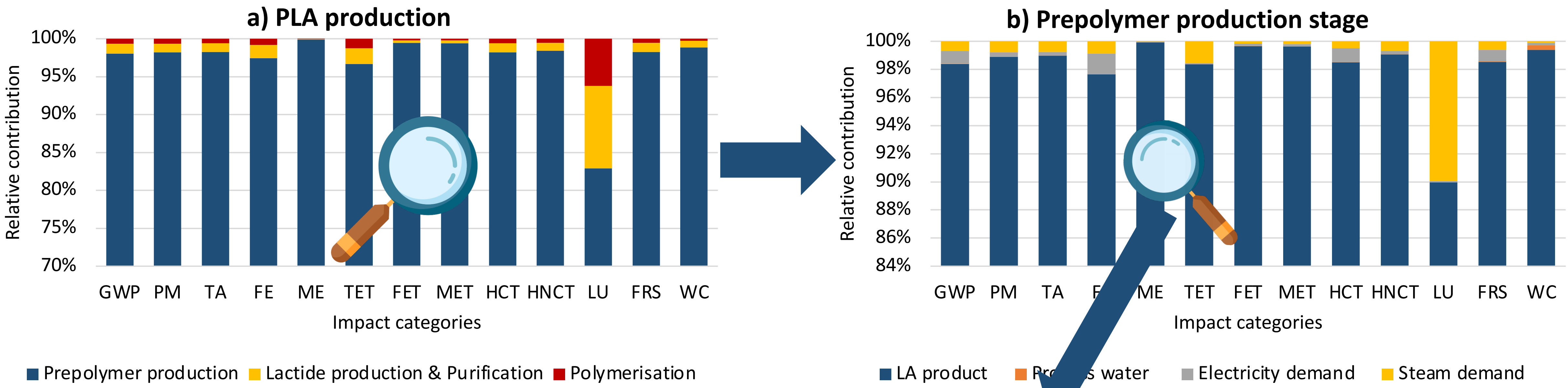


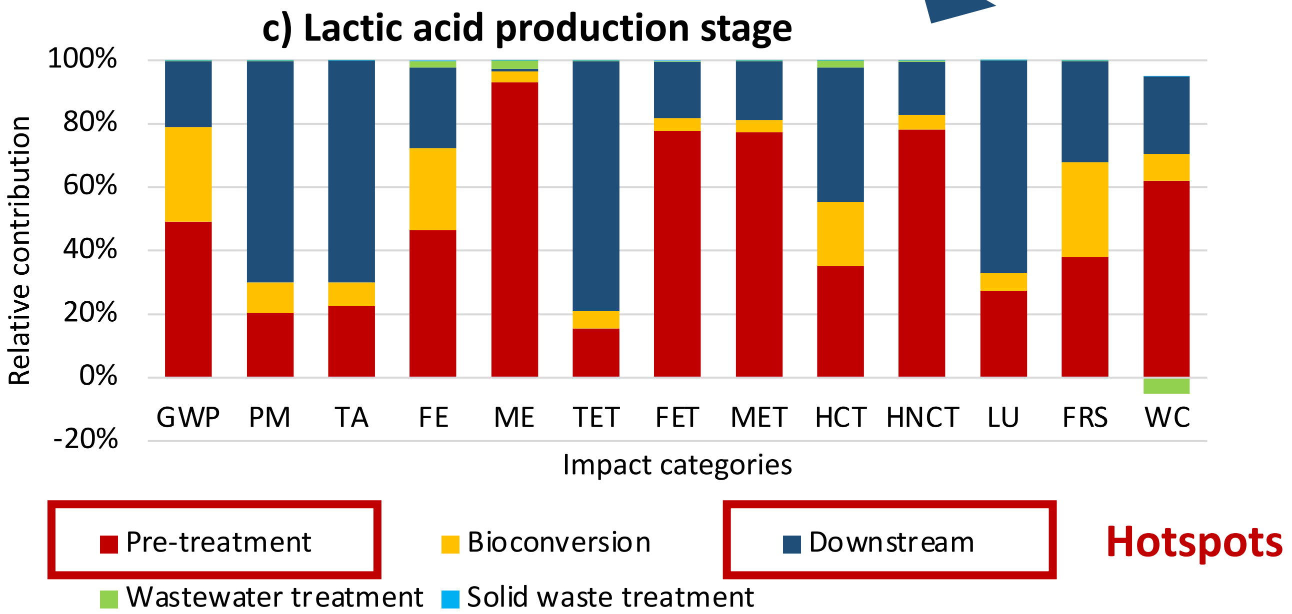
GWP profile per kg of PLA from literature and Ecoinvent v3.8 database

Feedstock	kg CO_2eq
Glucose syrup	0.95
Corn stover	1.04
Sugar beet pulp	2.25
Maize	2.83 - 3.05
Polypropylene	2.00



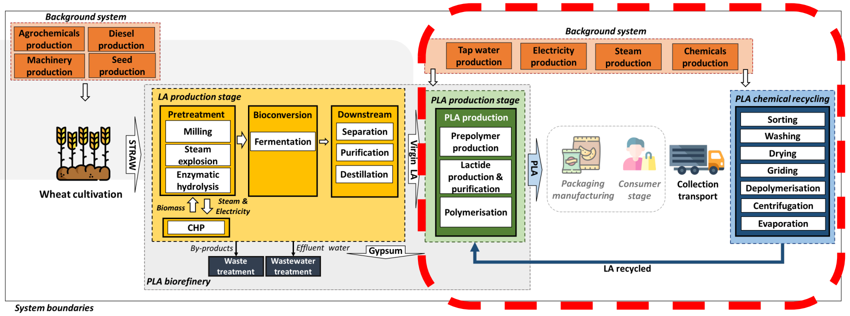
Contribution analysis



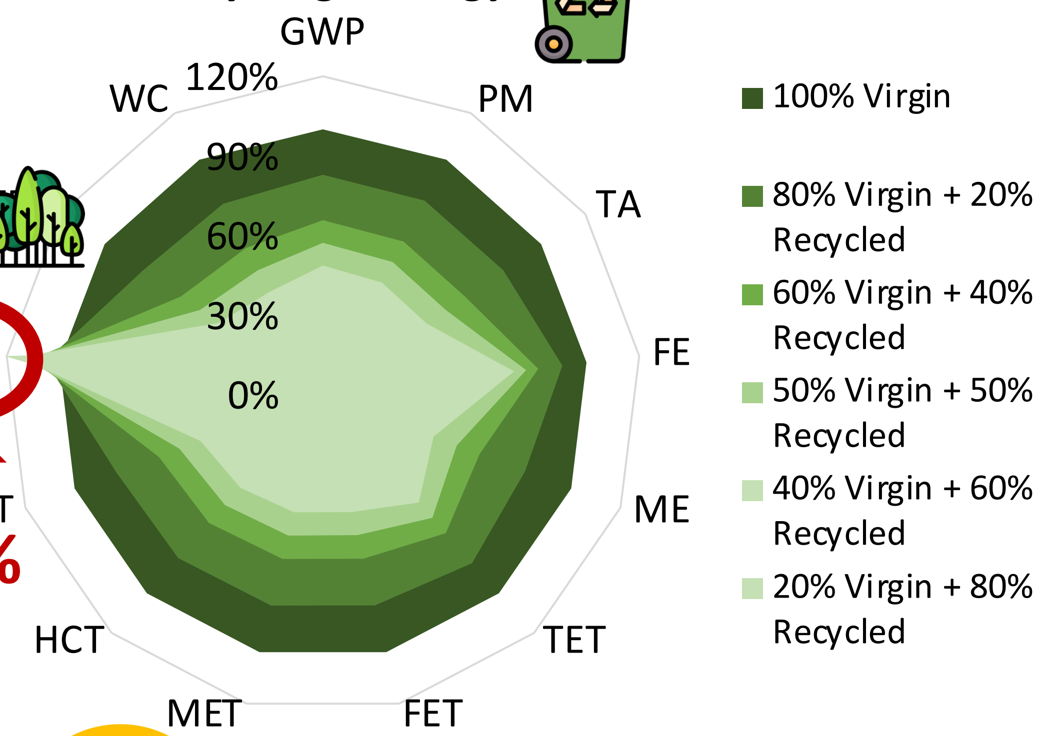


GWP	Global warming
PM	Fine particulate matter formation
TA	Terrestrial acidification
FE	Freshwater eutrophication
ME	Marine eutrophication
TET	Terrestrial ecotoxicity
FET	Freshwater ecotoxicity
MET	Marine ecotoxicity
HCT	Human carcinogenic toxicity
HNCT	Human non-carcinogenic toxicity
LU	Land use
FRS	Fossil resource scarcity
WC	Water consumption

PLA end-of-life



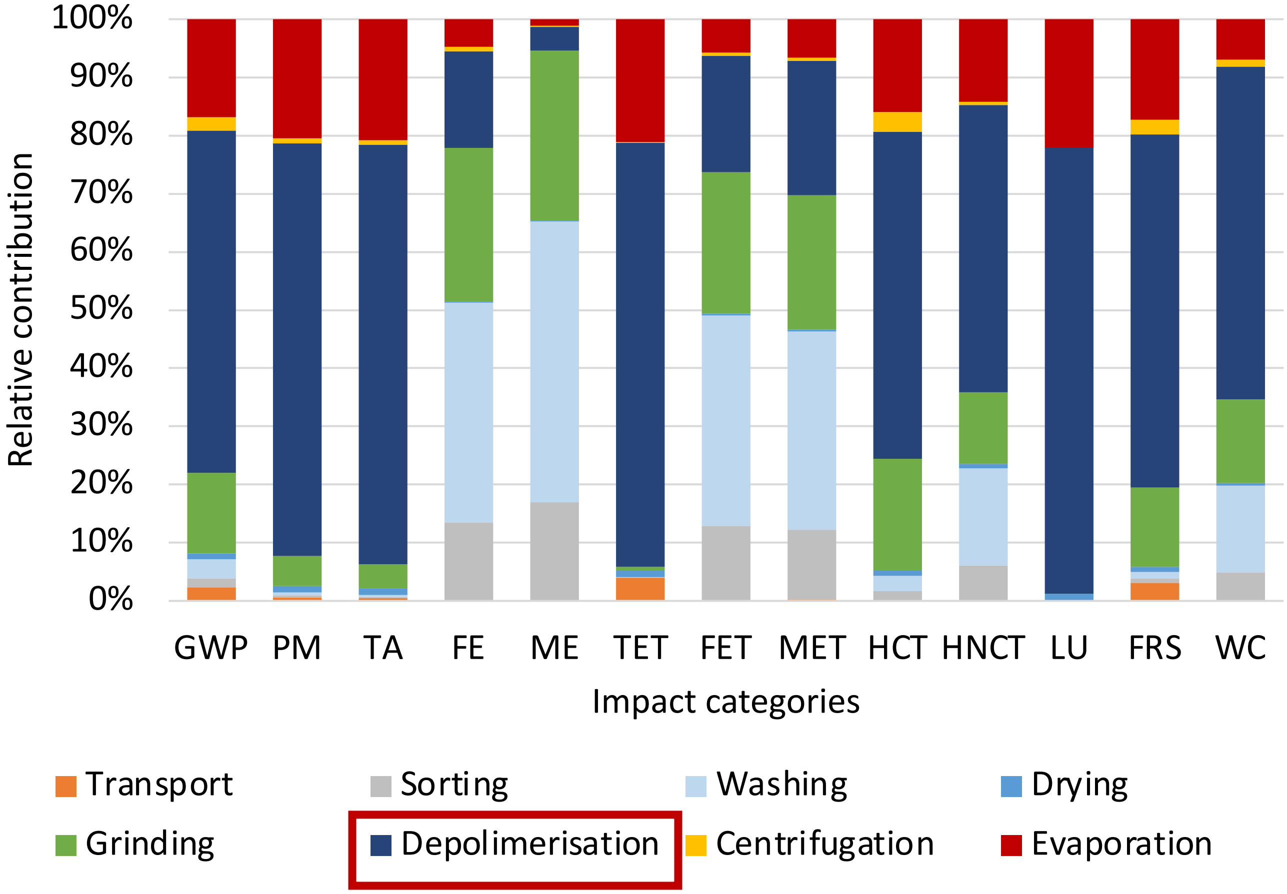
Chemical recycling strategy



21%

70% 1.42 to 0.45 kg CO_2eq

75% 0.12 to 0.03 m^3



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Conclusions

Straw biomass is a **valuable feedstock** for producing PLA.

Straw-PLA reached better results than its fossil counterpart and first generation route.

The **pre-treatment method** is a relevant issue in the environmental performance of this system.

Depolimerization it the most **important environmental load,** when thinking about **reclycling PLA.**

Energy demand is a critical factor in the environmental performance of bioproducts. The **use of renewable sources** can improve their profile.

LCA is a helpful tool to analyse the **environmental burdens** of valorisation route at early design of biorefinery systems

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