PROSPECTIVE LIFE CYCLE ASSESSMENT OF CELLULOSE NANOFIBRILS WITH ENZYMATIC PRETREATMENT

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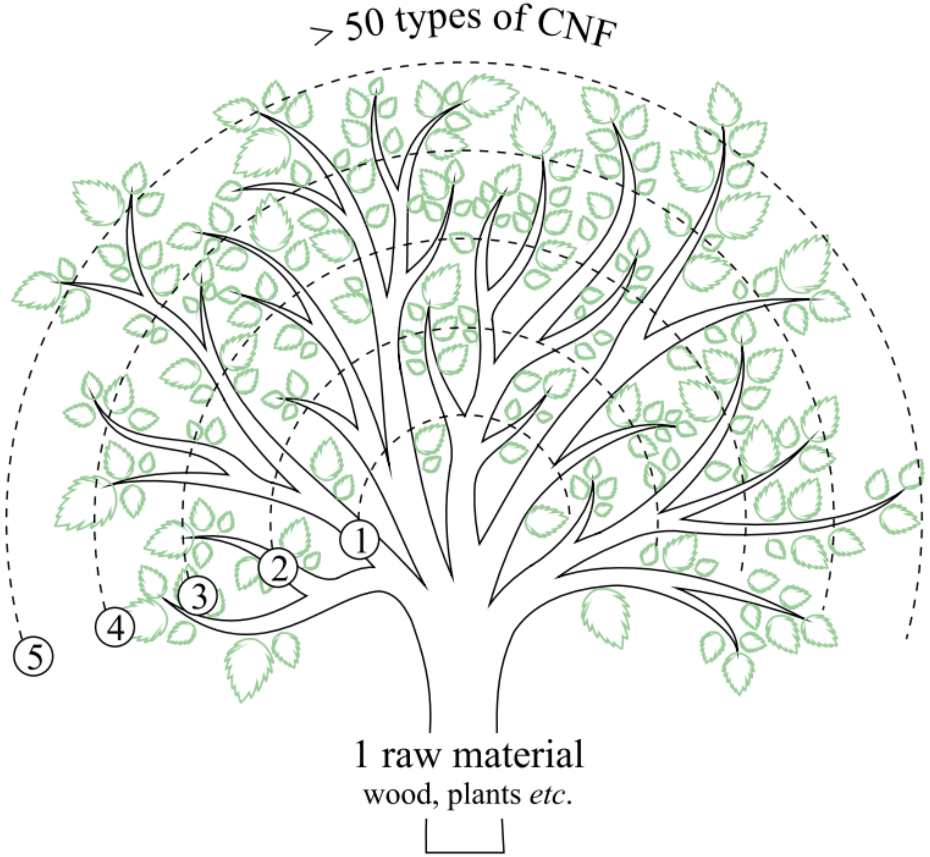
CNF PRODUCTION

① Purification
cooking and bleaching

② Mechanical pretreatment
– blending;
– refining;
– grinding.

③ Biological/chemical pretreatment
– enzymatic hydrolysis;
– carboxylation;
– carboxymethylation;
– quaternization;
– sulfonation;
– solvent-assisted pretreatment.

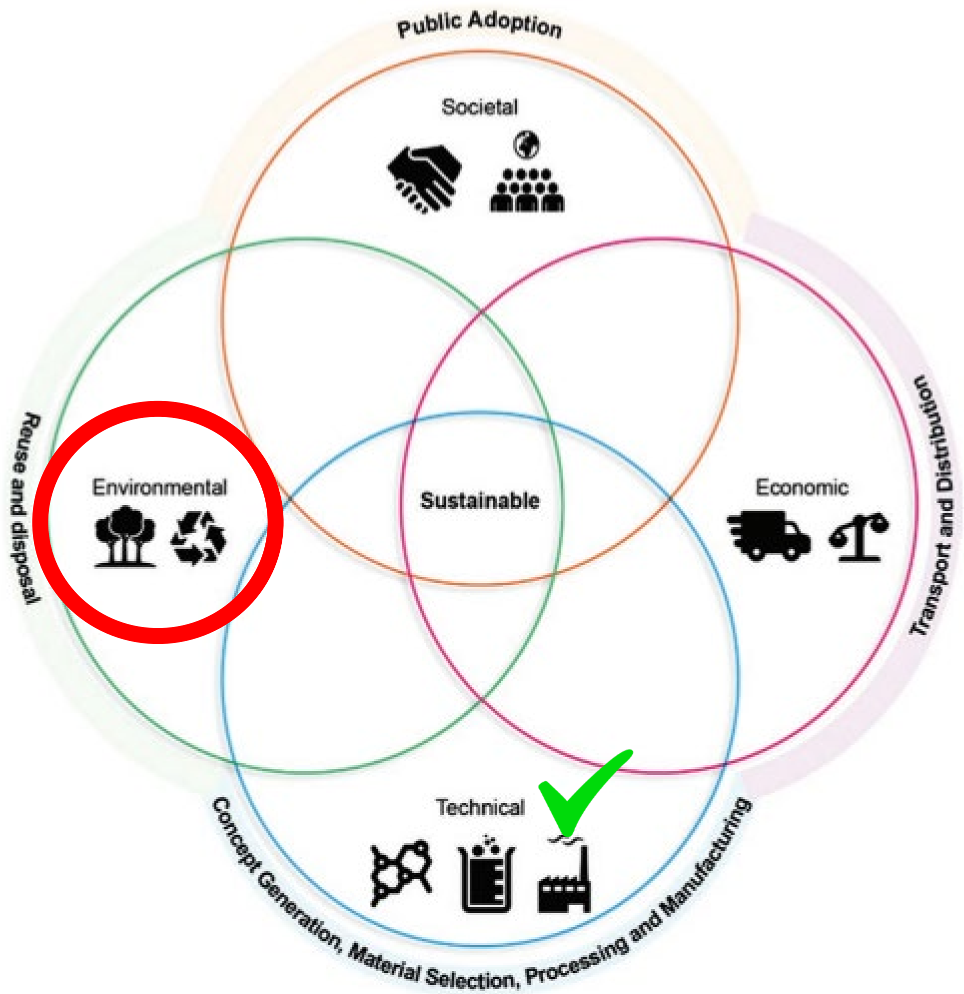


④ Principal mechanical treatment
– homogenization;
– grinding;
– refining;
– extrusion;
– blending;
– ultrasonication;
– cryocrushing;
– steam explosion;
– ball milling;
– aqueous counter collision.

⑤ Post-treatment
– chemical modification;
– fractionation.

SOURCE: Nechyporchuk et al. Ind.Crops.Prod. 2016, 93, 2-25

CNF is a sustainable material?



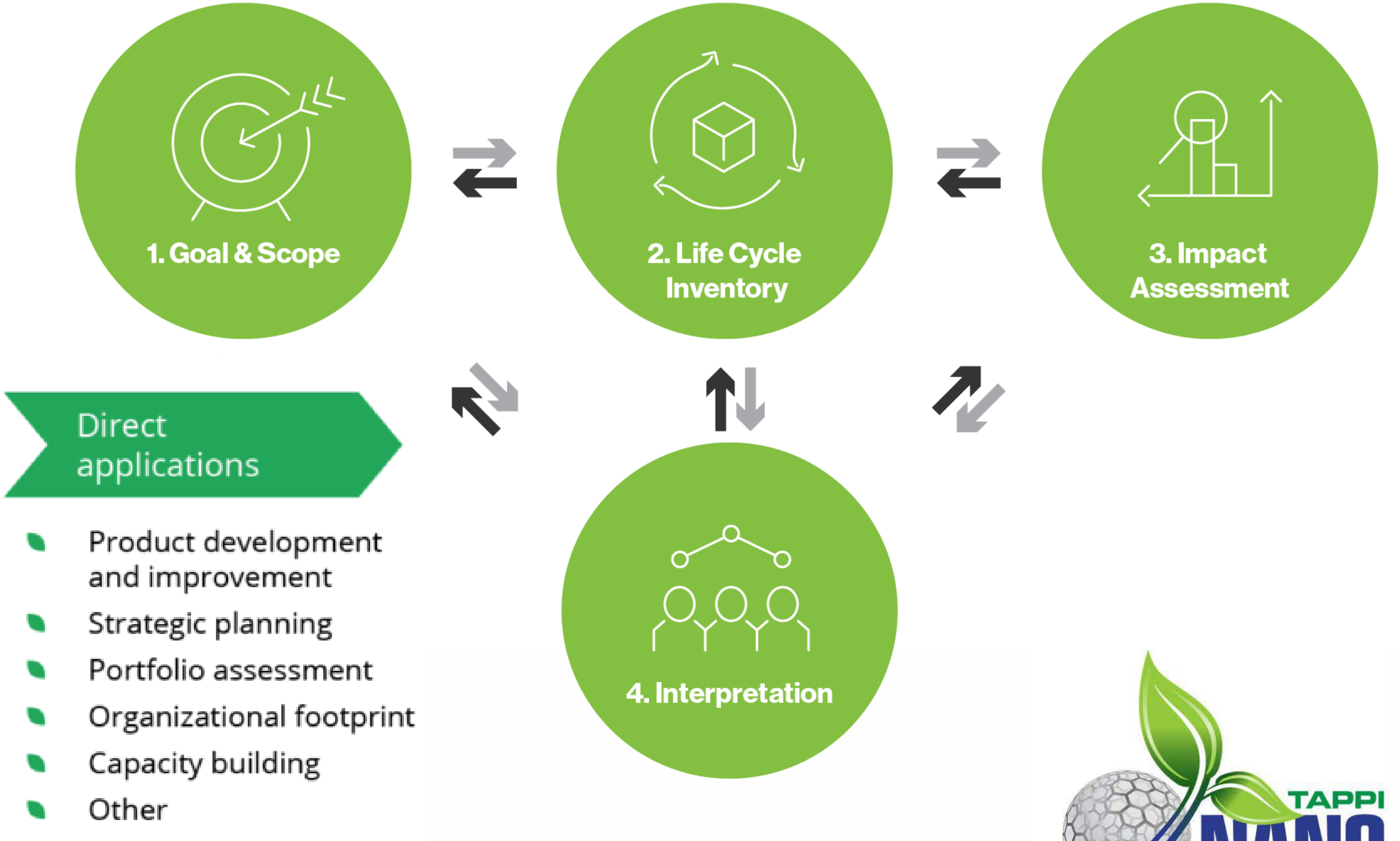
SOURCE: Datta et al. Adv.Mater. 2022, 32, 2100939

Renewable source → Processing → Biodegradable material?

How to measure its environmental sustainability?

LIFE CYCLE THINKING / LIFE CYCLE ASSESSMENT

SOURCE: https://pre-sustainability.com/articles/life-cycle-assessment-lca-basics/



SOURCE: https://www.rit.edu/sustainabilityinstitute/blog/what-life-cycle-assessment-lca

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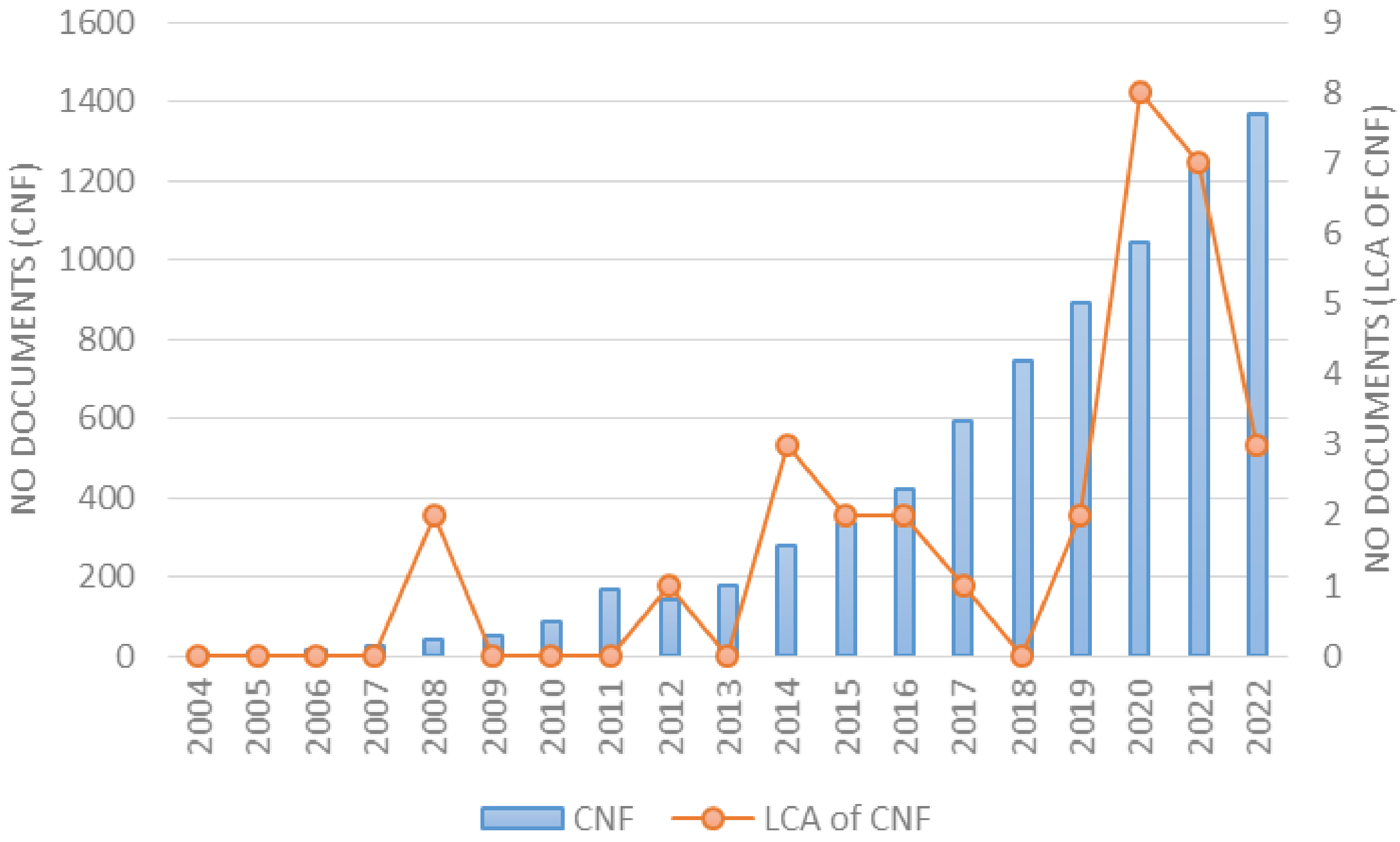
INTEREST IN CNF and LCA of CNF



Data Source: Scopus
Keywords (search 1): "cellulose nanofib*" OR "cellulose microfib*"
Keywords (search 2): "cellulose nanofib*" OR "cellulose microfib*" AND "life cycle assessment" OR "life cycle analysis"

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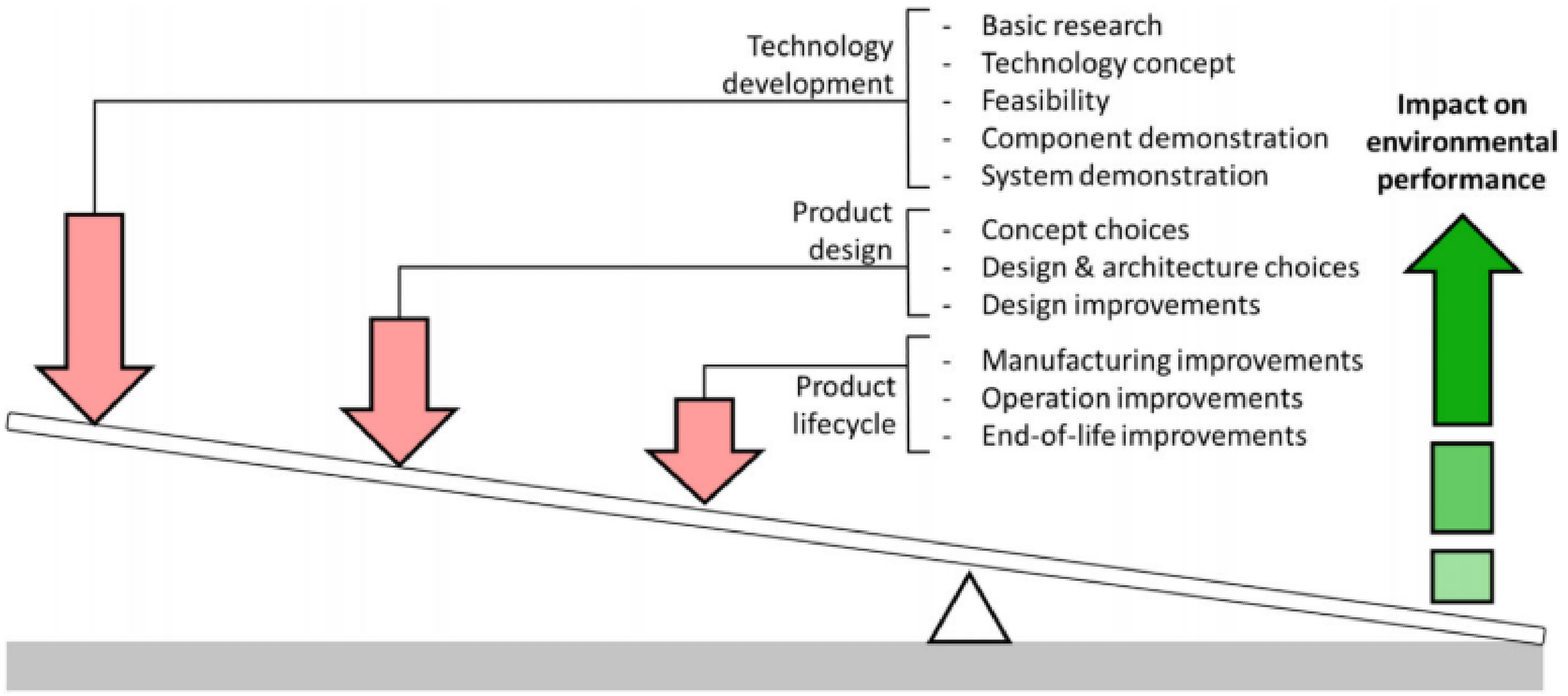
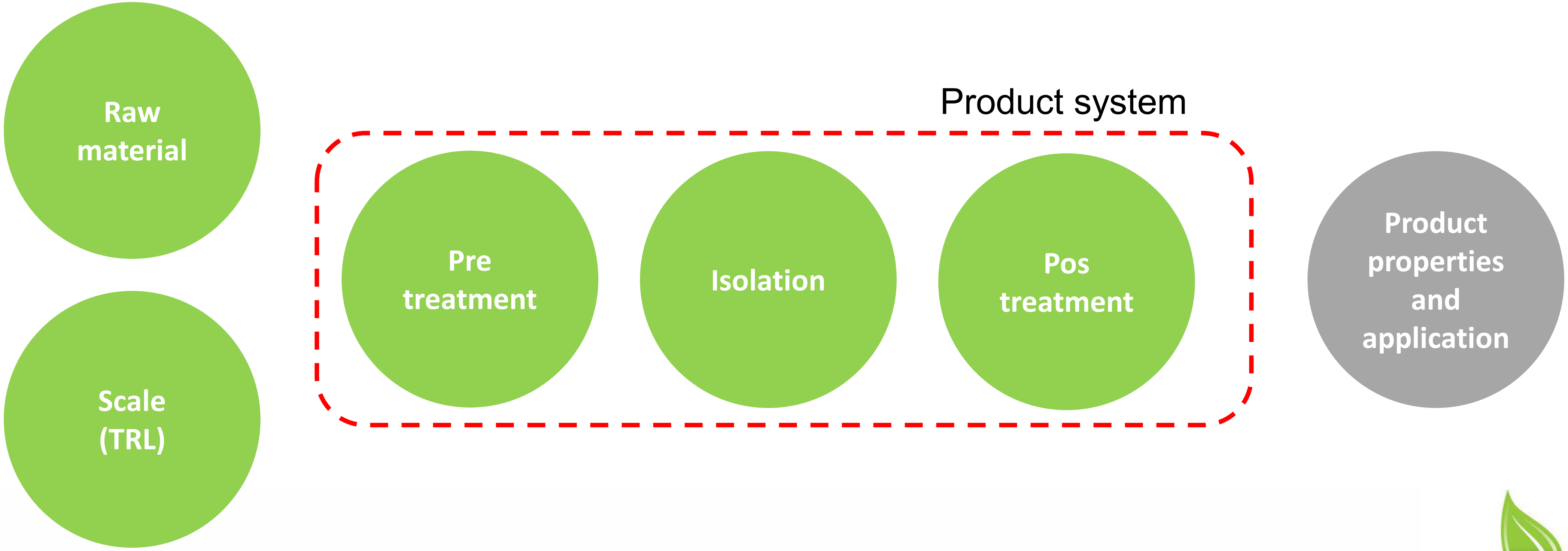
PROSPECTIVE LCA



SOURCE: Moni et al. J.Ind.Ecol. 2020, 24, 52-63

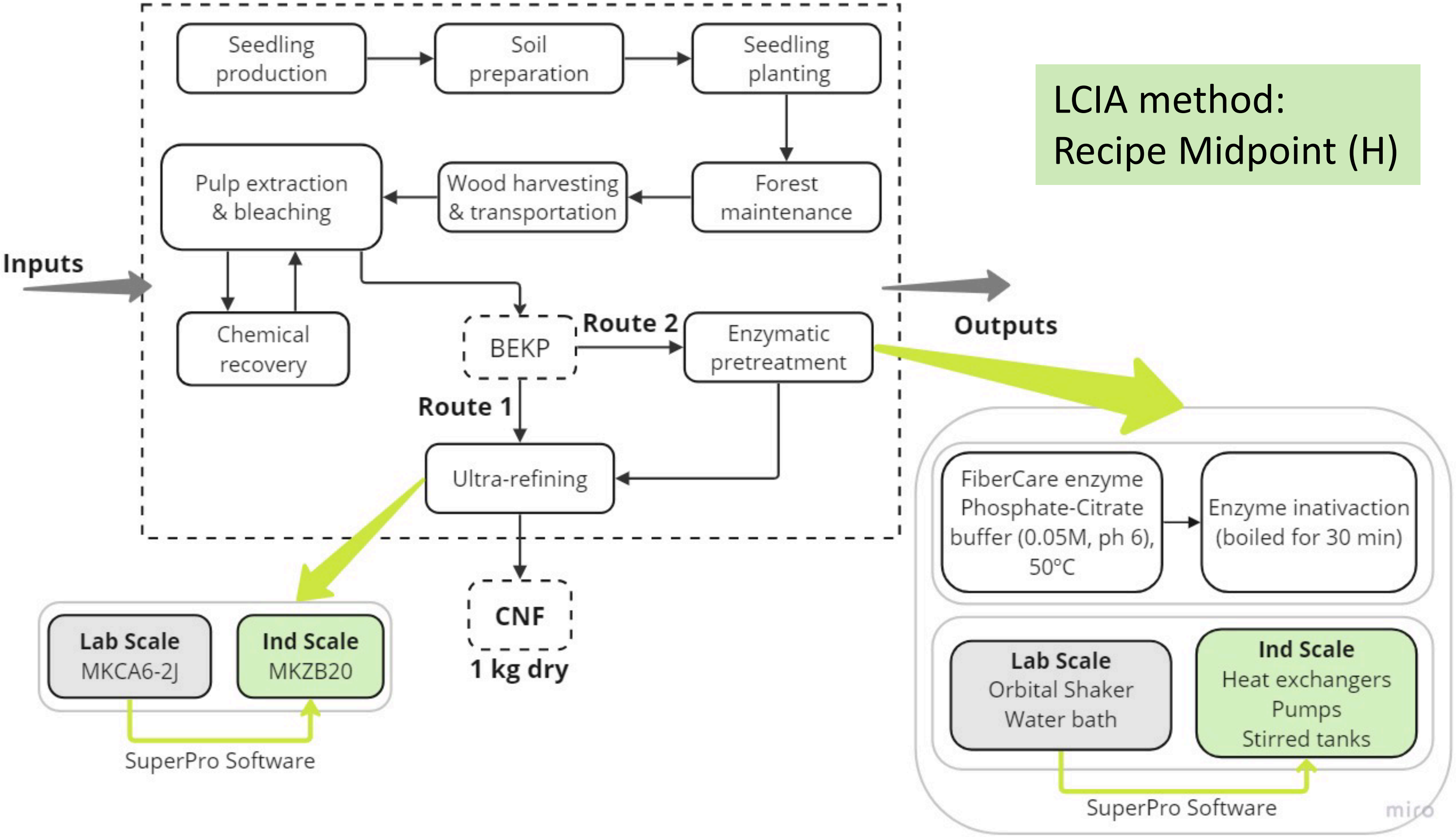
INFLUENCING FACTORS



System Boundaries

1. Goal & Scope

LCIA method:
Recipe Midpoint (H)



2. Life Cycle Inventory

- **Foreground data**
  Laboratory scale: laboratory experiments (Berto et al., 2021)
  Industrial scale: Simulation (SuperPro Software)

  Main inputs:

  Route 1:
  pulp, water, electricity

  Route 2:
  pulp, water, electricity,
  buffer, enzyme

Single-Step Fiber Pretreatment with Monocomponent Endoglucanase: Defibrillation Energy and Cellulose Nanofibril Quality

Gabriela L. Berto, Bruno D. Mattos, Orlando J. Rojas,* and Valdeir Arantes*

- **Background data**
  Ecoinvent database (2023)

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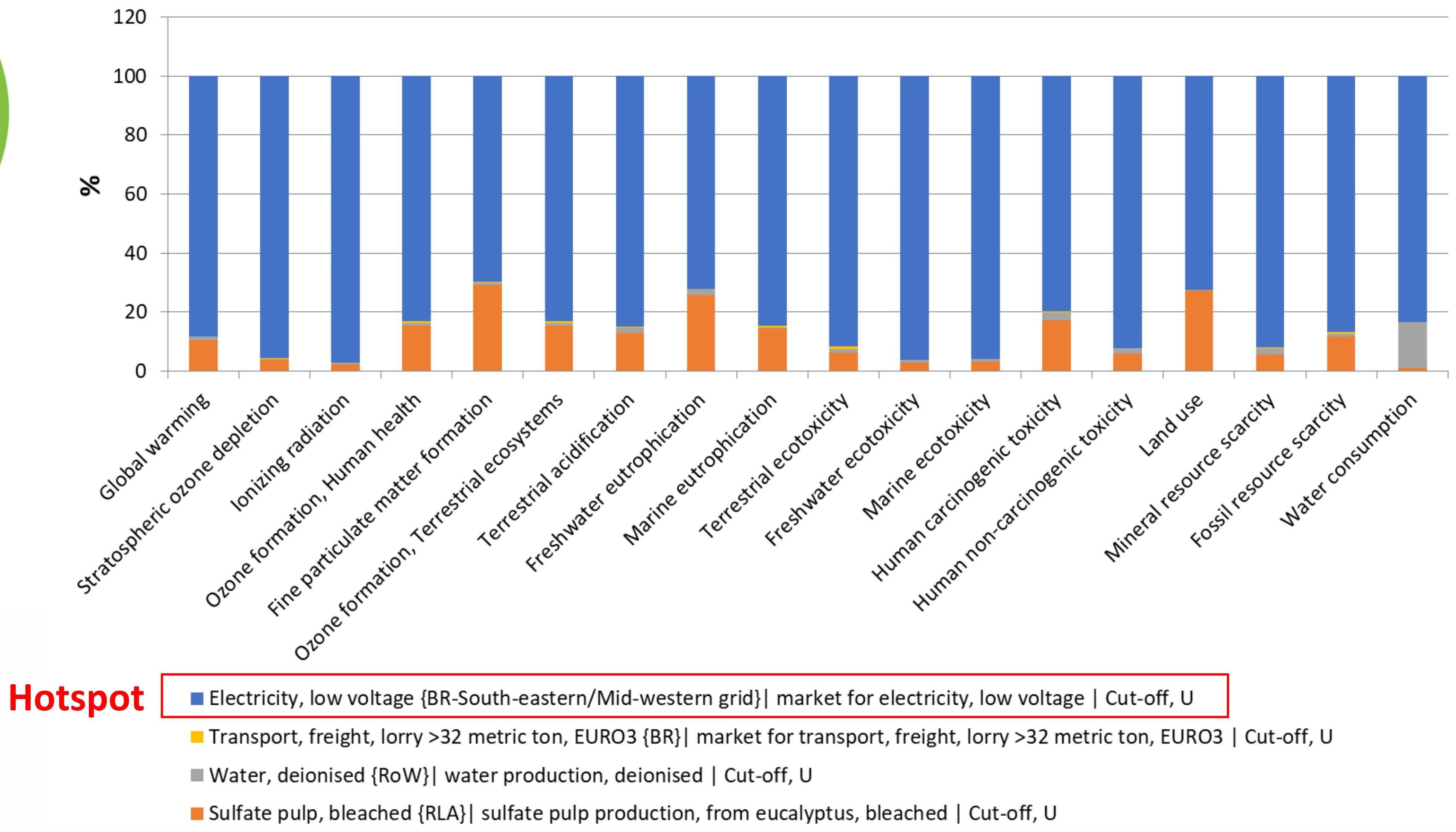
Route 1 (no pretreatment, Laboratory Scale)

3. Impact Assessment



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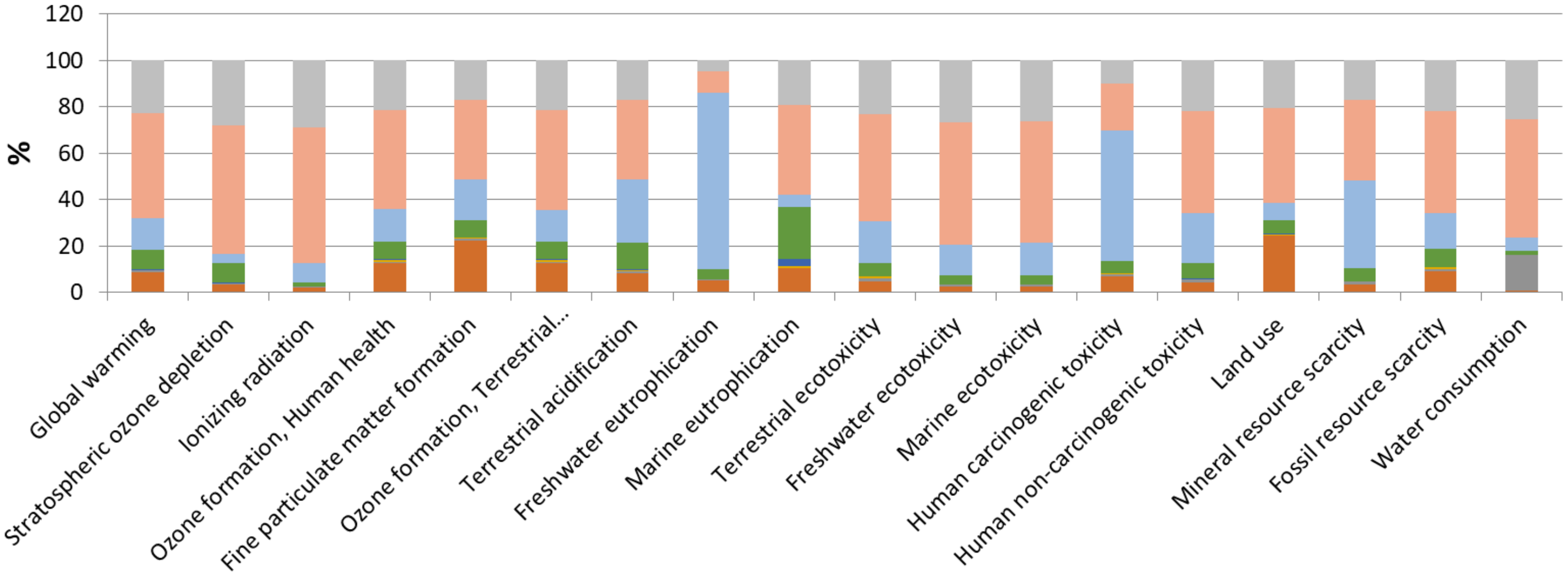
Route 2 (enzimatic pretreatment, Laboratory Scale)

3. Impact Assessment



Hotspots

- pretreatment - Electricity, low voltage {BR-South-eastern/Mid-western grid}| market for electricity, low voltage | Cut-off, U
- isolation - Electricity, low voltage {BR-South-eastern/Mid-western grid}| market for electricity, low voltage | Cut-off, U
- Trisodium phosphate {GLO}| trisodium phosphate production | Cut-off, U
- Citric acid {RoW}| citric acid production | Cut-off, U
- Enzymes {RoW}| enzymes production | Cut-off, U
- Transport, freight, lorry >32 metric ton, EURO3 {BR}| market for transport, freight, lorry >32 metric ton, EURO3 | Cut-off, U
- Water, deionised {RoW}| water production, deionised | Cut-off, U
- Sulfate pulp, bleached {RLA}| sulfate pulp production, from eucalyptus, bleached | Cut-off, U

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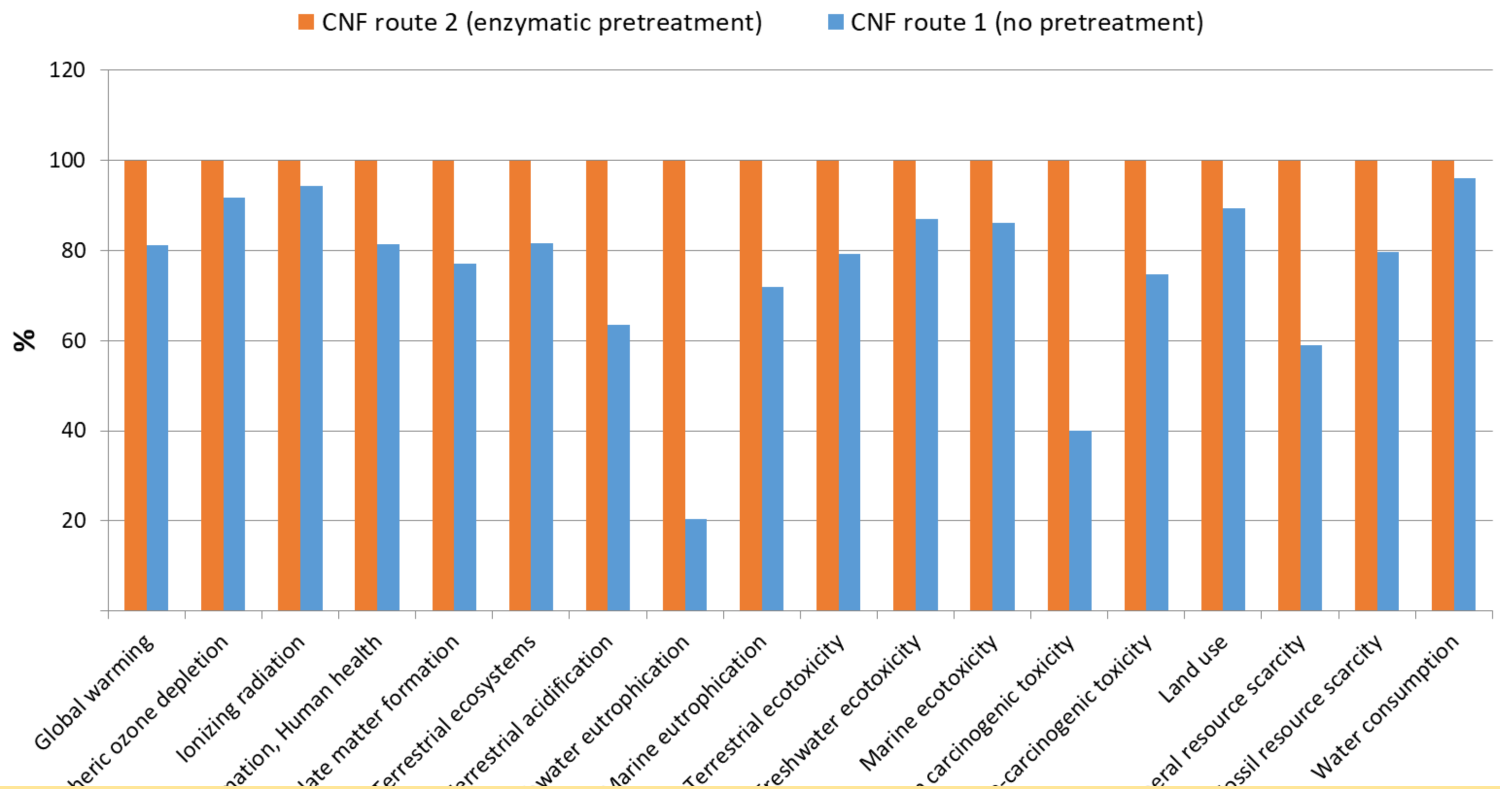
Route 1 vs Route 2 (Laboratory Scale)

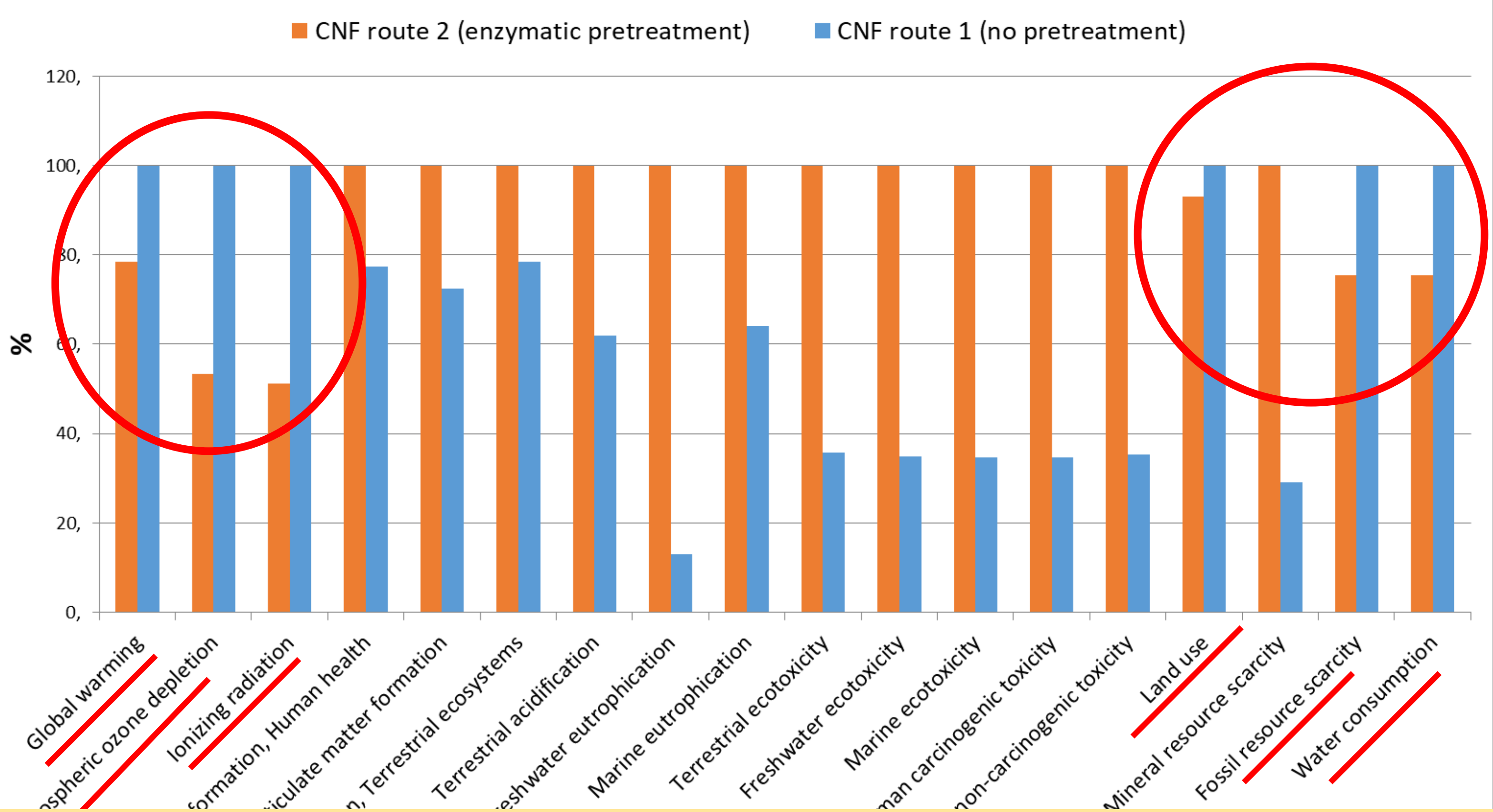
3. Impact Assessment



At lab scale, enzymatic pre-treatment increases the environmental impacts of CNF

Route 1 vs Route 2 (Industrial Scale)

3. Impact Assessment



The reduction in electricity consumption associated with enzymatic pre-treatment **on an industrial scale** implies a reduction in the highlighted impact categories

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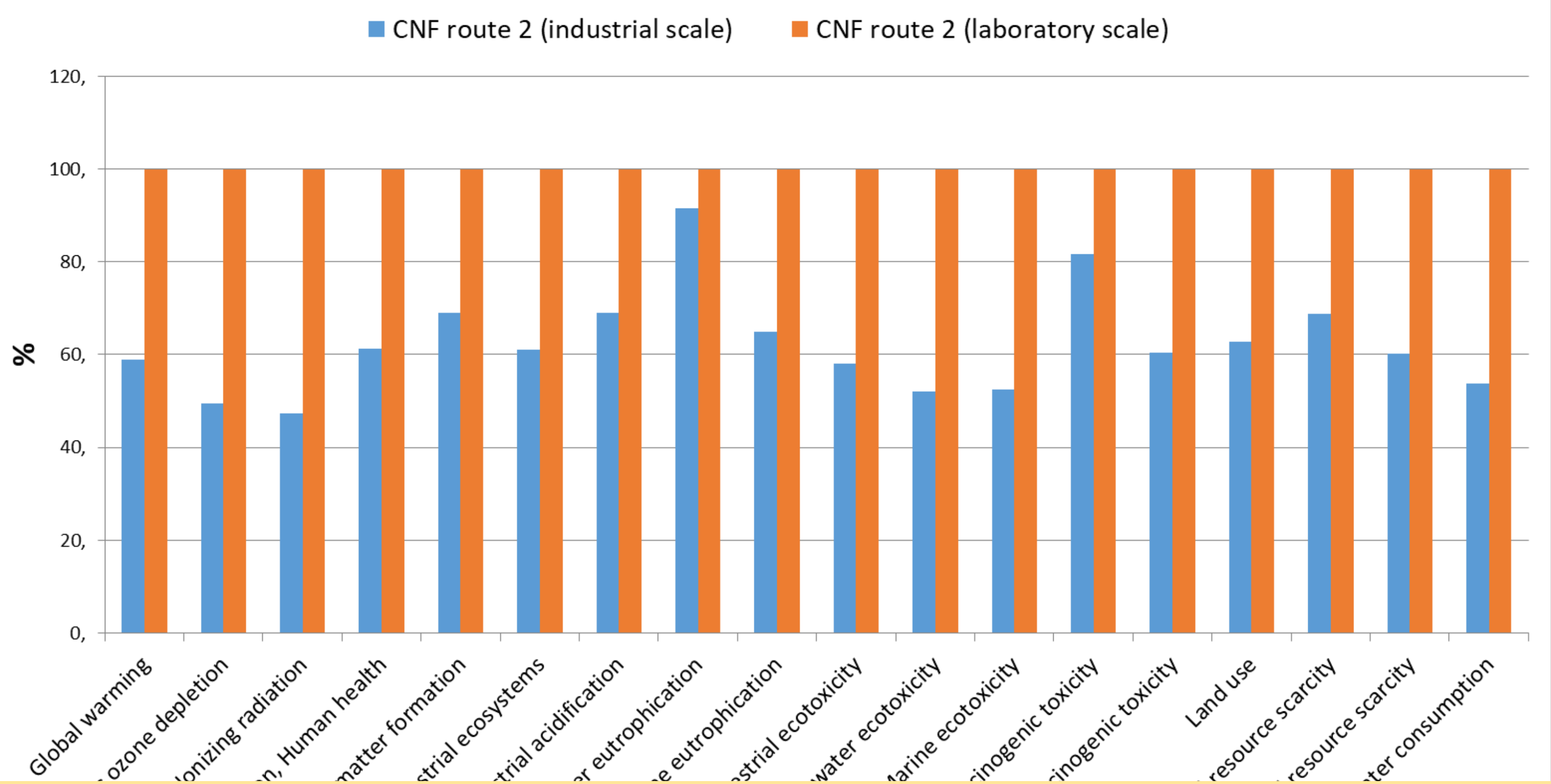
Route 2: Laboratory Scale vs Industrial Scale

3. Impact Assessment



The scale-up resulted in a significant decrease in electricity consumption for pretreatment and mechanical defibrillation

Comparison with other studies

4. Interpretation

Reference		This study		Arvidsson et al. (2015)*		Stampino el al. (2021)
Scale		Lab scale		Pilot Scale		Lab scale
Cellulose source		bleached hardwood kraft pulp	bleached hardwood kraft pulp	unbleached sulfate pulp	unbleached sulfate pulp	bleached hardwood kraft pulp
Impact categories	Unit	enzymatic (FiberCare R) + ultra-refining	ultra-refining	enzymatic (Novozym 476) + microfluidization	homogenization	enzymatic (FiberCare R)+ homogenization
Global warming	**kg CO_2 eq**	**5.7973**	**4.7072**	**0.79**	**1.2**	**930**
Stratospheric ozone depletion	kg CFC11 eq	1.29E-05	1.19E-05			1.27E-04
Terrestrial acidification	**kg SO_2 eq**	**0.0266**	**0.0169**	**0.0078**	**0.0069**	
Freshwater eutrophication	kg P eq	0.00554	0.0011			0.271
Marine eutrophication	kg N eq	0.0006	0.0004			0.795
Water consumption	**m^3**	**0.6358**	**0.6110**	**0.24**	**0.13**	**1945**

The environmental impacts of this study are in similar ranges to published studies with low environmental impact CNFs

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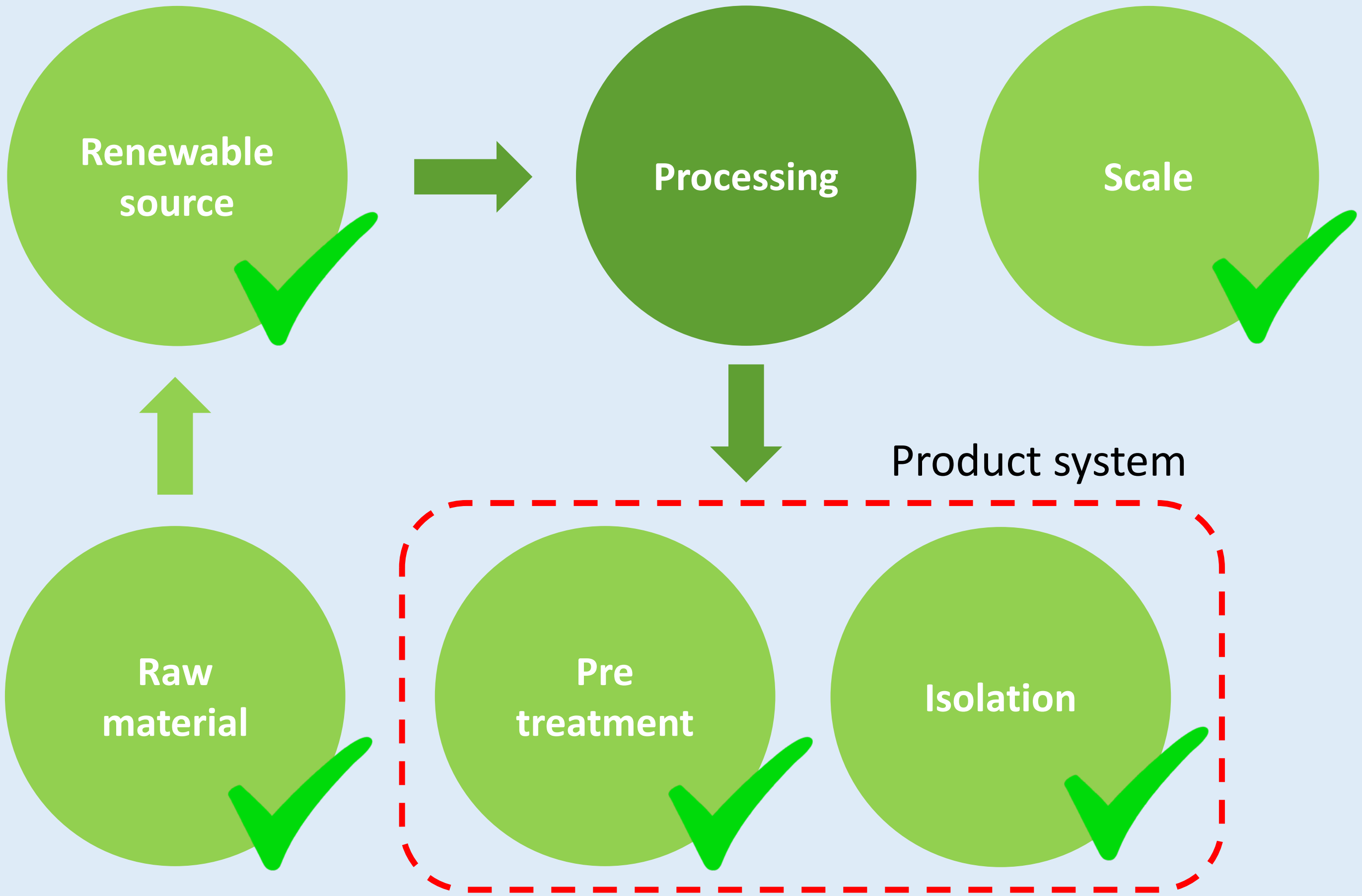
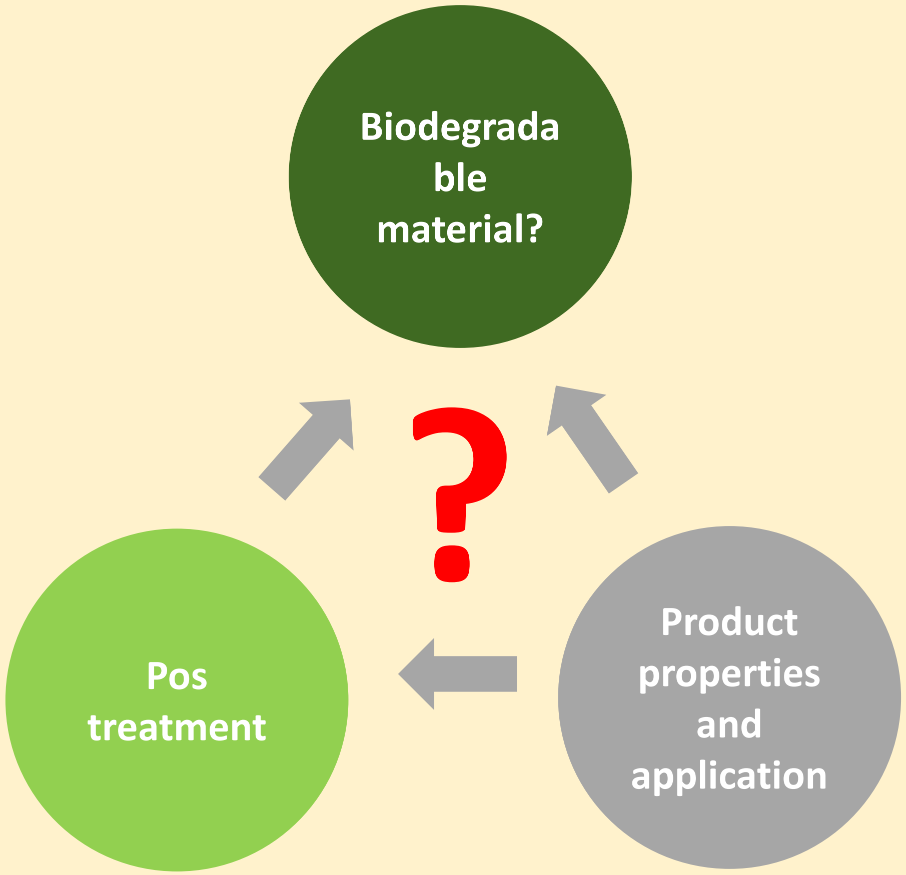
CNF is an environmentally sustainable material?

Comparison with other CNF types



Comparison with other materials



CONCLUSIONS

- HOTSPOTS OF LABORATORY AND INDUSTRIAL SCALE OF CNF PRODUCTION HAVE BEEN IDENTIFIED: ELECTRICITY AND BUFFER
- ENZYMATIC PRETREATMENT AT LABORATORY SCALE CAN BE IMPROVED USING ECODESIGN
- ENZYMATIC PRETREATMENT AT INDUSTRIAL SCALE IS MORE ENVIRONMENTALLY SUSTAINABLE WHEN COMPARED TO LABORATORY SCALE (LOWER ELECTRICITY CONSUMPTION)
- ENZYMATIC PRETREATMENT AT INDUSTRIAL SCALE IS MORE ENVIRONMENTALLY SUSTAINABLE FOR SOME CATEGORIES WHEN COMPARED TO NO PRETREATMENT (GLOBAL WARMING, WATER USE, FOSSIL RESOURCE SCARCITY, LAND USE, IONISING RADIATION AND STRATOSPHERIC OZONE DEPLETION)
- NEED TO EXPAND THE STUDY BOUNDARY TO ASSESS THE USE AND DISPOSAL OF CNFs

TAKE-HOME MESSAGES

LCA AS TOOL FOR ECODESIGN IN A LOW TRL PROCESS

HOTSPOTS IDENTIFICATION

SCALE-UP CONSIDERING ENVIRONMENTAL IMPACTS

A SUSTAINABLE BIOECONOMY GOES BEYOND BIO-BASED PRODUCTS

THE SUSTAINABLE TRANSFORMATION OF RENEWABLE BIORESOURCES TO HIGH-VALUE BIO-BASED PRODUCTS IS ESSENTIAL