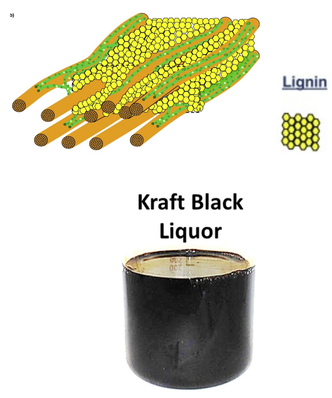
Lignin valorisation: Life Cycle Assessment considerations for enabling Circular Bioeconomy

Angeliki Kylili, Paris Fokaides

School of Engineering, Frederick University, Cyprus

1. Introduction

Lignin is the sole renewable aromatic resource that is found in abundance on Earth and does not call into question the ethics of diverting land from food to energy production. However, the conversion of lignin into added-value bio-products, bio-chemicals or biofuels is a challenging field from technological, environmental and economic perspectives. This work focuses on the identification of the critical environmental aspects that will provide reliable evidence in support of lignin valorisation routes for the production of value-added products and bioenergy.



Lignin is a hydrocarbon comprising 8-20% of the secondary cell wall of terrestrial plants

The black liquor contains 30–34% of lignin and is the main by-product of the Kraft process.

Lignin will also form the main constituent of large residual streams in the future cellulose ethanol plants and biorefineries.

2. Life cycle assessment of lignin valorisation

Life Cycle Assessment (LCA) provides the best framework for determining the whole life-cycle environmental performance of the promising lignin valorisarion routes as well as suggests alternatives for the attainment of the most sustainable chains.

There is a very limited number of LCA studies on the valorisation of lignin to added-value products resulting in the lack of validated information and quantified data on the environmental performance of lignin valorisation.

The findings of LCA lignin valorisation studies indicate:

- lignin-based versus conventional products/ practises:
  - decreased GHG emissions, global warming, energy, ecotoxity
  - increased acidification, eutrophication, ozone depletion, smog
- environmental burdens arise due to the complex lignin structure that requires intense operational conditions and strong solvents for its de-polymerisation and its further processing to value-added commodities
- challenges in the practical implementation of LCA studies, ie. high dependency of results on type of lignin resource, conversion routes, production yields

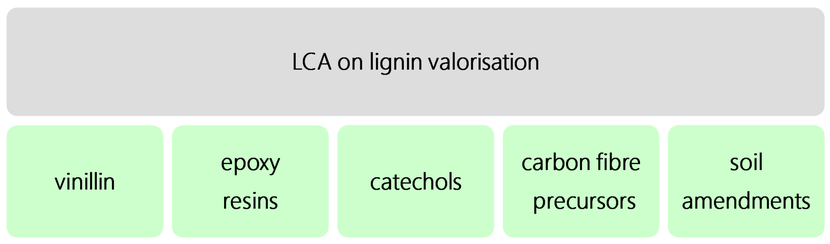


Figure: Lignin valorisation end-products investigated through life cycle assessment methodologies

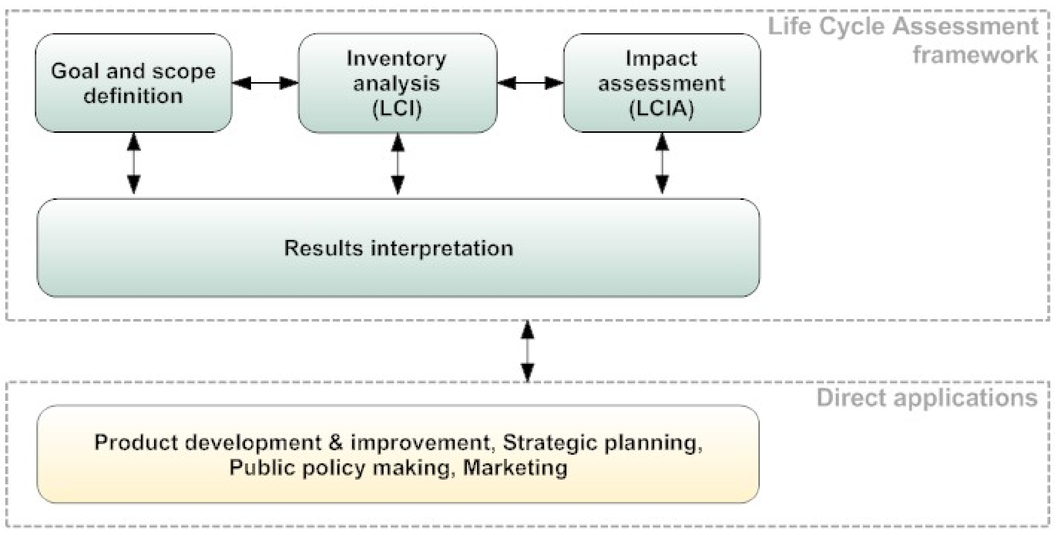


Figure: Principles of life cycle assessment as specified by the international standards ISO 14040 and ISO 14044

3. Lignin valorisation under the context of circular bioeconomy

Circular Bioeconomy is defined as the intersection of bioeconomy and circular economy; building on the synergies of the two concepts.

Although both concepts have common objectives, complementary approaches and contribute to one another, they also have a number of differences. The further analysis of synergies and divergences among the concepts is crucial for fulfilling significant societal objectives.

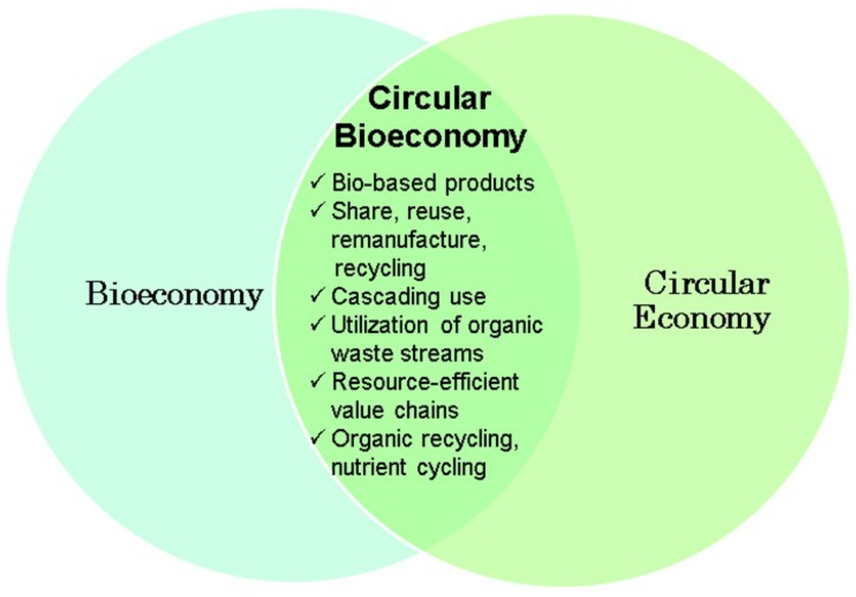


Figure: Circular Bioeconomy

As a co-product of the pulp and paper industry and its potential in increasing its added value through its valorisation to aromatics, polymers, high-performance materials and composites, lignin has a significant position in the novel concept of circular bioeconomy. LCA studies have validated the contribution of lignin-based products to sustainable development in terms of energy usage and GHG emissions.

Despite its environmental benefits, lignin valorisation also gives rise to controversial aspects such as it fits under the one concept but comes in contradiction with the values of the other.

Key considerations that should be taken into account in the development of the future biorefineries include:

- Emissions to water: impact of lignin washing wastewater and lignin leaching from end products on aquatic environments
- Emissions to air: atmospheric pollution from the transportation of large quantities of biomass to processing plants — future biorefineries should be based on decentralised models with small and flexible units
- Land use: direct and indirect land use changes as a result of the anticipated demand for the lignin fraction for the production of added-value products

4. Concluding remarks

Despite the limited availability of information and data on the environmental performance of lignin valorisation, lignin is expected to play a significant role in the future biorefineries. Nonetheless, biorefineries should be assessed using holistic sustainable approaches, accounting for direct and indirect impacts across all levels and across the whole life cycle, since there are substantial barriers yet to be overcome from a technological, socioeconomic, environmental and political perspective.

Acknowledgements

The authors wish to acknowledge COST Action CA17128 "Establishment of a Pan-European Network on the Sustainable Valorisation of Lignin (LignoCOST)" for supporting the dissemination of this work via the ITC conference grant to the PhD student Angeliki Kylili.

Corresponding Author: Angeliki Kylili, https://www.serg-web.com/, +35722 394394, Frederick University, Cyprus