

Life Cycle Carbon Analysis Of Packaging Products Containing Non-wood Residues

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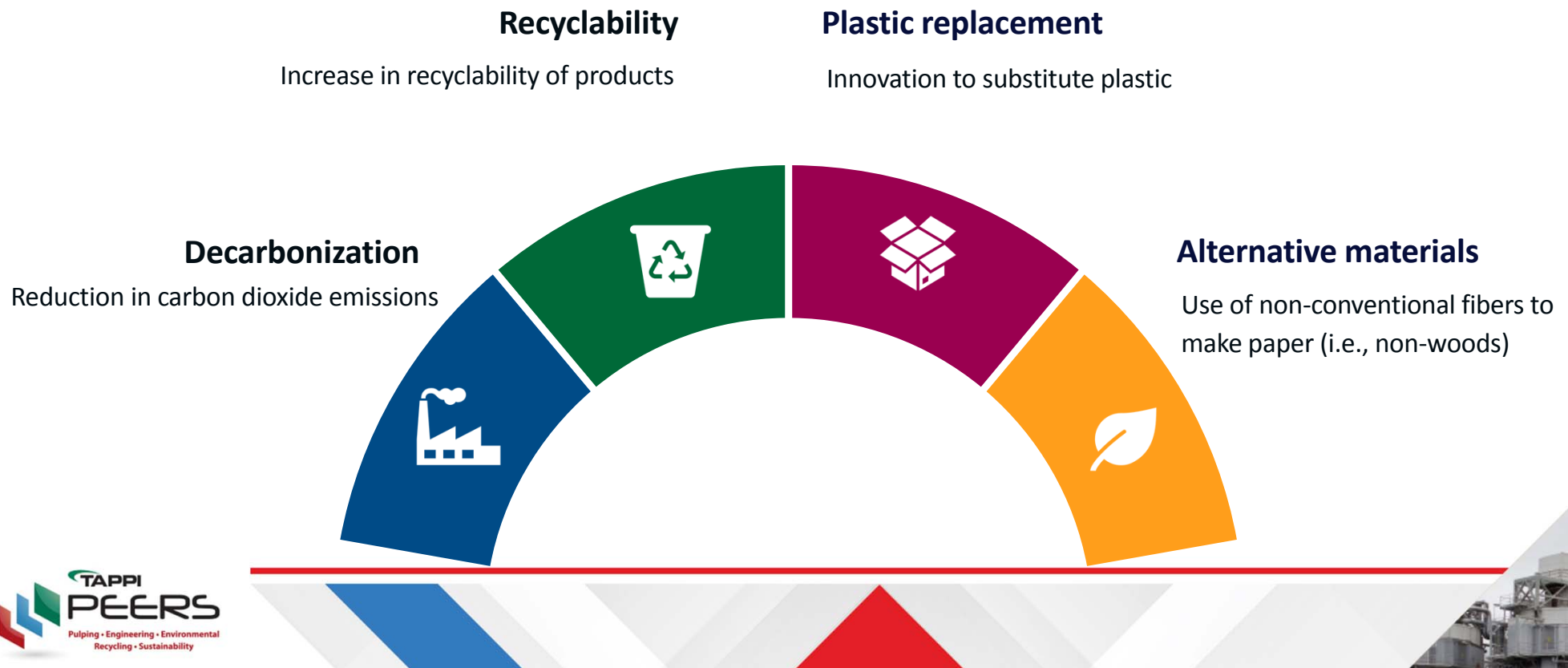


Agenda

- Motivation of this work
- Objectives
- Methodology
- Results
 - Life Cycle Carbon Analysis (LCCA) of non-wood residues
 - Life Cycle Carbon Analysis (LCCA) of linerboard containing non-wood residues – Cradle-to-gate
 - Effect of product performance on the Life Cycle Carbon Analysis (LCCA) of linerboard containing non-wood residues
 - Life Cycle Carbon Analysis (LCCA) of linerboard containing non-wood residues – Cradle-to-grave



Sustainability trends in the pulp and paper industry - Packaging

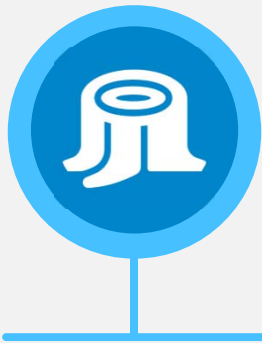


Non-wood fibers



PERCEPTION

- Increase in customers' attention on non-wood fibers **perceived by them** to offer unique and positive benefits compared to wood sources.



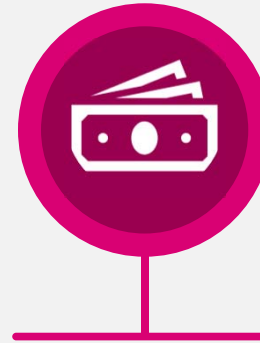
MARKETING

- Marketing of non-wood fibers has been focused on deforestation.
- The P&P industry in North America does not contribute to deforestation¹⁻³.



SUPPLY CHAIN

- There is not enough national supply of non-wood fibers (very region specific - unstable).
- Possible supply from other countries (China: Bamboo...).



COST

- Higher cost associated with non-wood fibers.



RECYCLABILITY

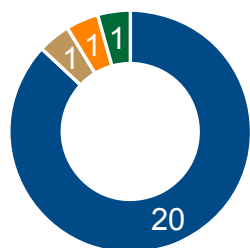
- Recyclability of some non-wood fibers has been reported to be lower than wood fibers⁴.

¹Two Sides. (2018). "In North America, we grow many more trees than we harvest." <https://twosidesna.org/paper-production-supports-sustainable-forest-management/> (accessed in April 2023). ²Fisher International. (2020). "Pulp & Paper Products Consume 50% of Harvested Timber in US." <https://www.fisheri.com/blog/pulp-paper-products-consume> (accessed in April 2023). ³Forest2Market. (2017). "Historical Perspective on the Relationship between Demand and Forest Productivity in the US South." https://www.forest2market.com/hubfs/2016_Website/Documents/20170726_Forest2Market_Historical_Perspective_US_South.pdf (accessed in April 2023). ⁴Jirarotepinyo et al. (2022). The Impact of multiple recycle loops on the yield and properties of softwood kraft fibers and of non-wood fibers for packaging TAPPI PEERS Conference Proceedings.



Non-wood residues: Current status

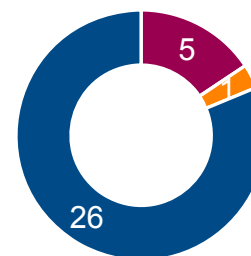
Lines producing 100% wheat straw pulp (by pulp type)*¹



■ Soda ■ CTMP ■ NSSC ■ CMP modified

Number of lines worldwide producing pulp from only wheat straw

Lines producing 100% bagasse pulp (by pulp type)*¹



■ Kraft ■ NSSC ■ Soda

Number of lines worldwide producing pulp from only sugarcane bagasse

- Non-woods represent ca. 1% of the global pulp production (straw and bagasse are the most used residues)¹.
- In the US, non-wood pulp is less than 0.1% of the total pulp production (linters and straw are the most used residues)¹.

*Including lines using only wheat straw or bagasse as raw materials

¹FisherSolve Next, 2022



Sustainability of non-wood residues: Literature Review

Wheat straw

- Studies focus on China (5) and Canada (1).
- 5 out of 6 studies do not consider any emissions for straw since it is considered a residue
- Pulping processes studied do not reflect the most efficient available processes:
 - $\text{NaOH} + \text{Na}_2\text{S}_2\text{O}_3$
 - Neutral ammonium sulfite
- Due to challenges for recovery, most papers assumed the use of black liquor as a fertilizer.
- Products: Market pulp, printing & writing, corrugated, tissue...
- Results show overall lower carbon footprint for wood-based products than straw-based.



Sustainability of non-wood residues: Literature Review

Sugarcane bagasse

- Studies focus on Thailand (2) and China (1).
- 2 out of 3 studies do not consider any emissions for bagasse since it is considered a residue.
- Pulping processes poorly described (or not described at all)
- Products: Market pulp, tissue, wrapping, molded products...
- No consensus on whether sugarcane-based paper has a lower carbon footprint than wood-based .

Overall challenges

- Geography plays an important role in the assessment.
- How to allocate the emissions of cultivation to these residues?
- There is a lack of updated/realistic technical information around the processing of these fibers.
- Sometimes, the comparison with wood is not fair (performance is not considered).



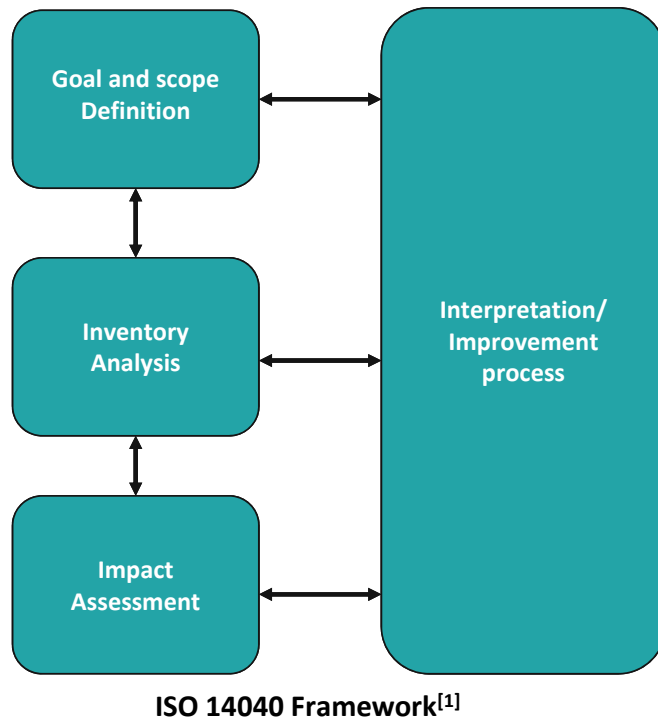
Objectives

- Understand the state-of-the-art knowledge on the life cycle carbon analysis of paper made from non-wood residues.
- Evaluate the life cycle carbon analysis (LCCA) of packaging made from wheat straw and sugarcane bagasse across the whole life cycle.
- Understand the effect of life cycle analysis (LCA) methodology on the LCCA results of packaging made from wheat straw and sugarcane bagasse.

Opportunity: Evaluate the environmental sustainability of non-wood residues (wheat straw and bagasse) transformed into the same product in the same geography (United States), under more realistic processes, and with the same LCA methodology (varying allocation methods).

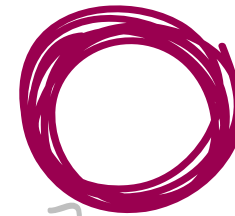


Methodology



Process flowsheet

- Product flows
- Emissions
- Raw materials
- Energy flows



Database of processes with inputs and outputs

Life cycle inventory

Life cycle impact analysis

Characterization factors to convert elementary flows into impacts

- Global warming
- Ozone depletion
- Acidification
- Eutrophication
- Smog
- Human health
- Ecotoxicity
- Human health
- Land-use
- Others

[1] International Organization for Standardization, "ISO 14040:2006 Environmental management - Life cycle assessment - Principles and framework." p. 20, 2006



Methodology

1

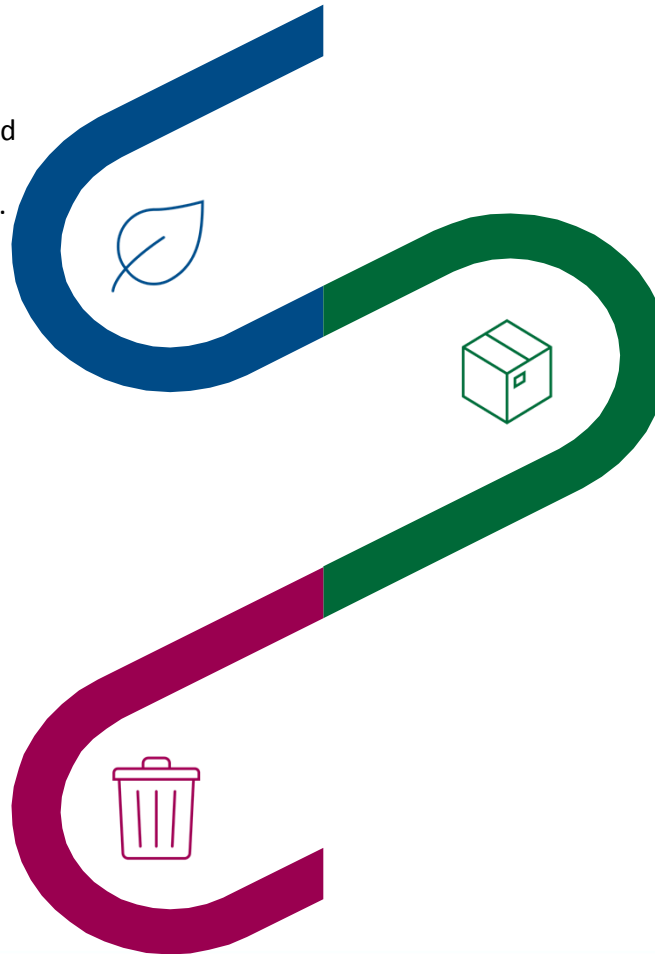
- **Goal:** Evaluate the GWP of wheat straw and sugarcane bagasse and understand the effect of allocation methods on the results.
- **Scope:**
 - **Boundaries:** Cradle-to-gate
 - **Functional unit:** 1 dry ton
 - **Data source:** USLCI, and Ecoinvent

3

- **Goal:** Evaluate the GWP of producing and disposing linerboard and corrugated medium containing non-wood wet lap pulp compared to wood-based paper.
- **Scope:**
 - **Boundaries:** Cradle-to-grave
 - **Functional unit:** 1 ton of paper
 - **Data source:** USLCI, Ecoinvent and FisherSolve Next

2

- **Goal:** Evaluate the impact on GWP of replacing wood fiber with non-wood mechanical wet lap pulp in linerboard and corrugated medium. The replacement rate was 30%. Also, the goal is to include the effect of product performance.
- **Scope:**
 - **Boundaries:** Cradle-to-gate
 - **Functional unit:** 1 ton of paper
 - **Data source:** USLCI, Ecoinvent and FisherSolve Next



LCCA of wheat straw and bagasse

1

- **Goal:** Evaluate the GWP of wheat straw and sugarcane bagasse and understand the effect of allocation methods on the results.

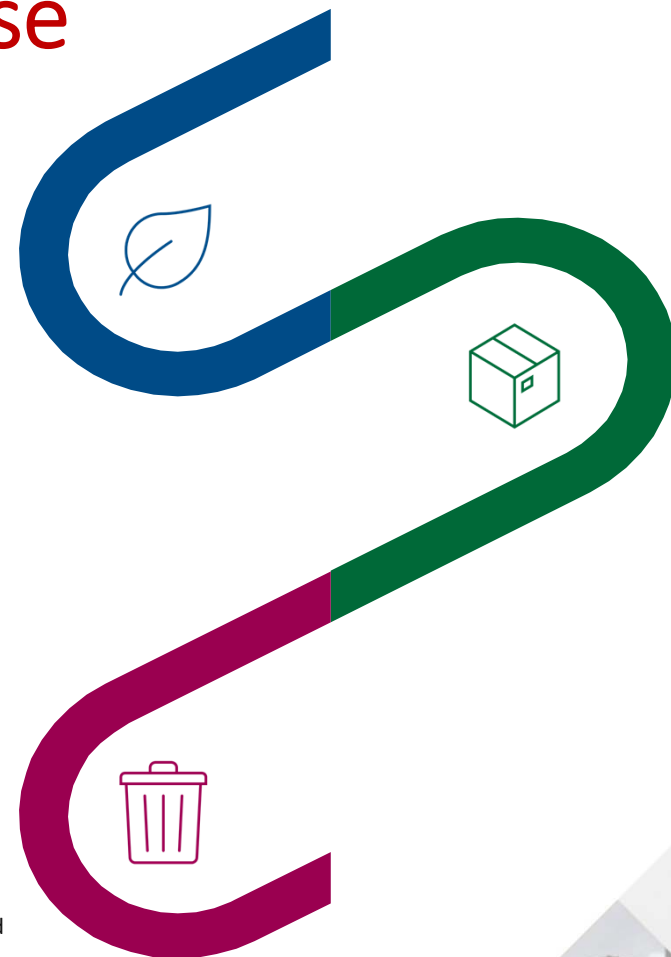
- **Scope:**

- **Boundaries:** Cradle-to-gate
- **Functional unit:** 1 dry ton
- **Data source:** USLCI, Ecoinvent, and literature

- How to deal with multi-functional non-wood fiber systems*? Allocation methods:

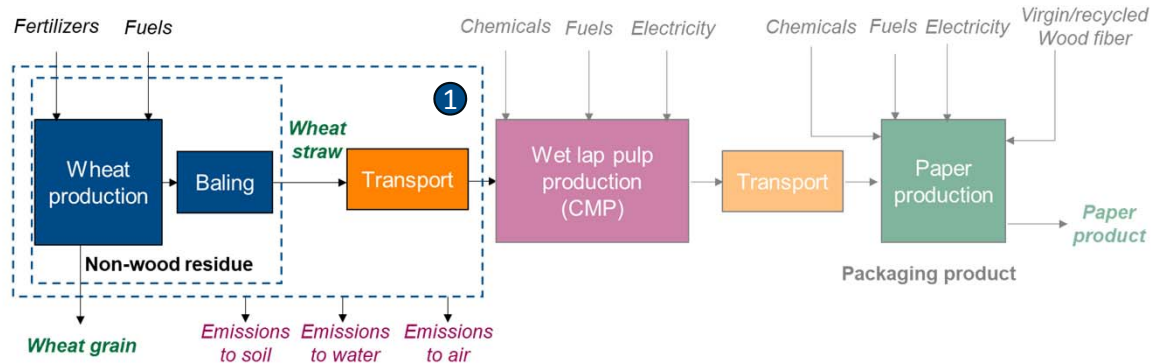
- **Cut-off (CO):** No emissions allocated to Ag residues (e.g. straw, bagasse).
- **System expansion (SE):** Additional emissions due to removing Ag residues from original system are allocated to Ag residues (e.g. additional fertilizer, fuels).
- **Mass allocation (MA):** Emissions are allocated based on mass basis (main product and Ag residues).
- **Economic allocation (EA):** Emissions are allocated based on economic basis

*Multi-functional systems produce more than one product. Therefore, total emissions need to be shared. Examples include wheat and wheat straw production or sugar, molasses and sugarcane bagasse production

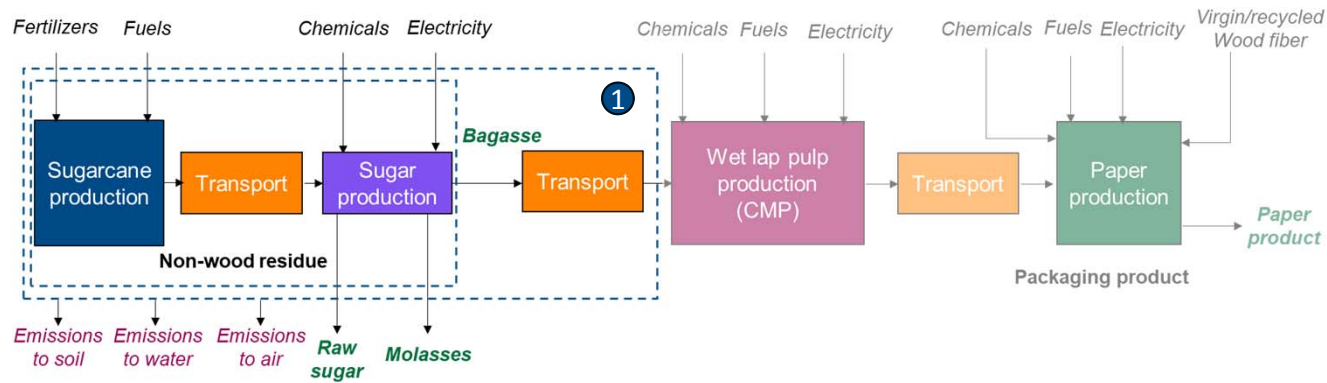


LCCA of wheat straw and bagasse

Wheat straw – System boundaries



Bagasse – System boundaries

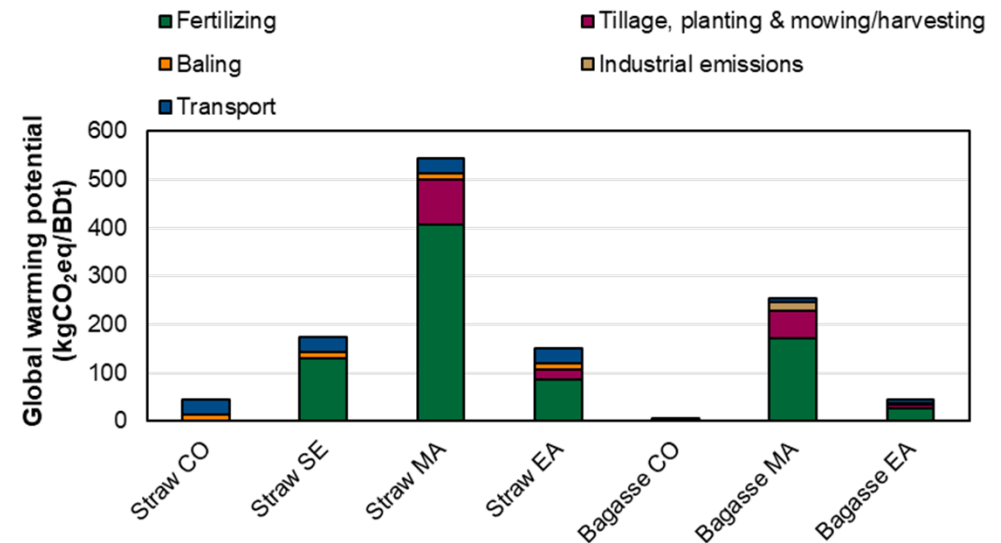


System boundaries for LCCA of wheat straw and sugarcane bagasse



LCCA of wheat straw and bagasse

- Results are highly dependent on allocation methods.
 - CO^a: Lower impacts. Only handling and transportation emissions are accounted for.
 - MA^b: Higher impacts. Primary product and residue share burdens based on mass.
- Fertilizers are the largest GWP contributors under SE^c, MA^b, EA^d.
- Transportation is the largest GWP contributor under CO^a.



Global warming potential for non-wood residues under different allocation methods

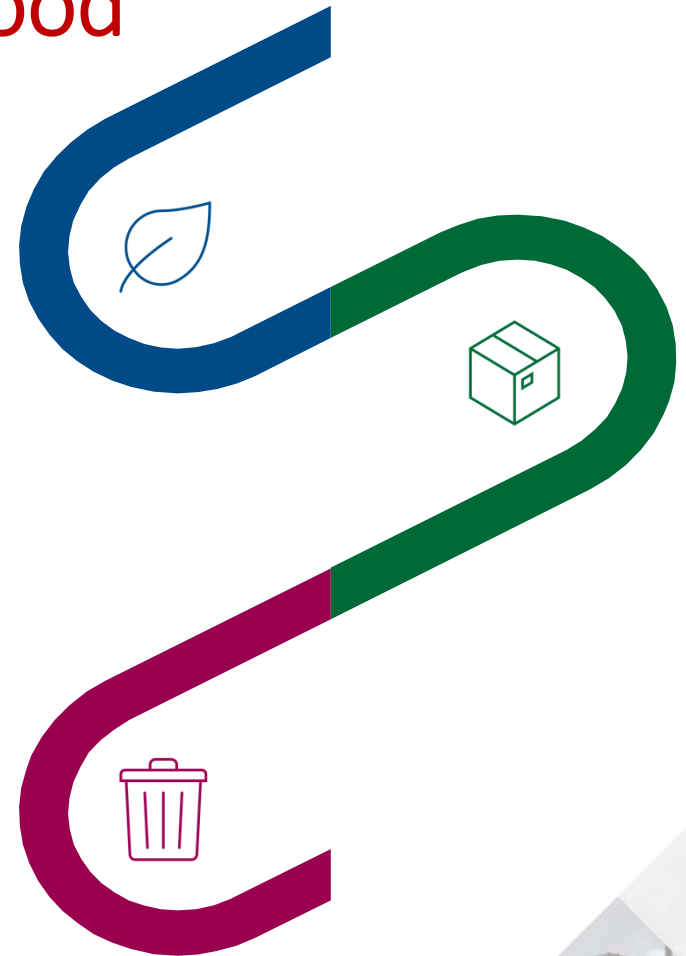
^aCO: Cut-off; ^bMA: Mass allocation ; ^cSE: System Expansion; ^dEA: Economic allocation



LCCA of linerboard from non-wood residues

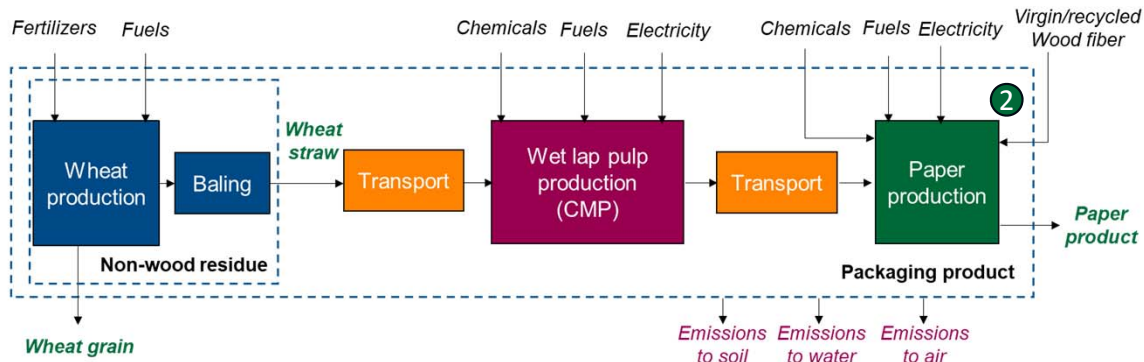
2

- **Goal:** Evaluate the impact on GWP of replacing wood fiber (30%) with non-wood mechanical wet lap pulp in linerboard and corrugated medium. Also, the goal is to include the effect of product performance.
- **Scope:**
 - **Boundaries:** Cradle-to-gate.
 - **Functional unit:** 1 ton of paper.
 - **Data source:** USLCI, Ecoinvent and FisherSolve Next.
- **Main assumptions:**
 - Two studied geographies: Northwest US (NWUS) and Southeast US (SEUS).
 - Data for wet lap non-wood pulp was obtained from FisherSolve Next and benchmarked against literature data.
 - Generic Ecoinvent processes were used for paper and modified based on wood substitution.

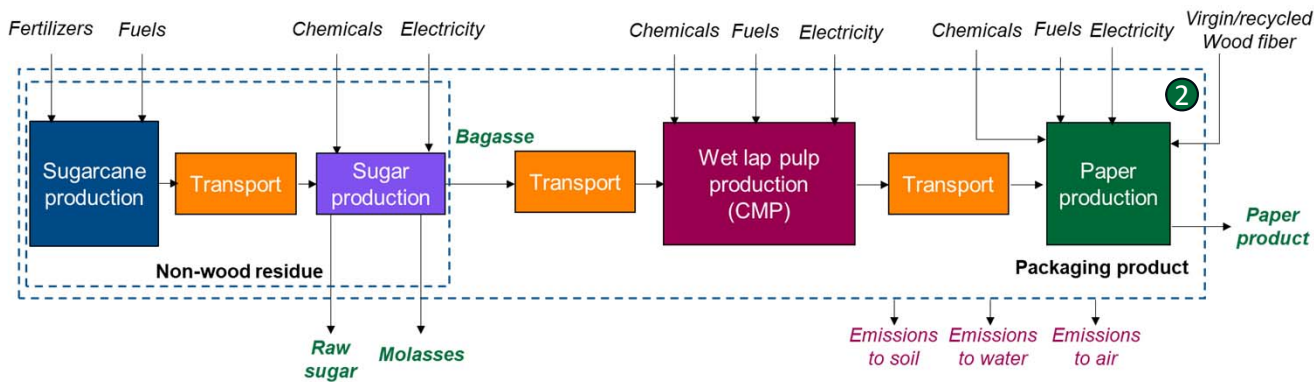


LCCA of linerboard from non-wood residues

Wheat straw – System boundaries



Bagasse – System boundaries

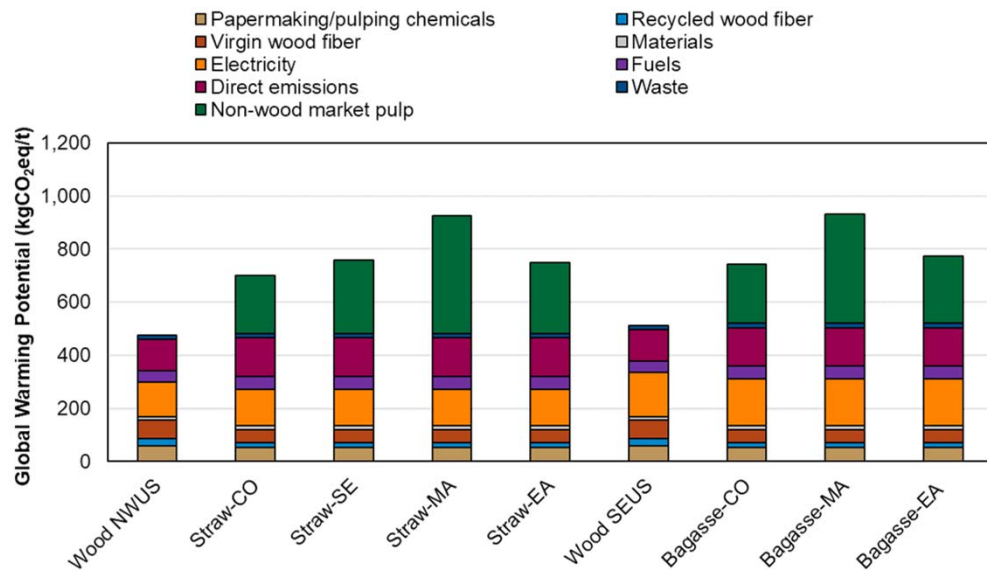


System boundaries for LCCA of paper made from non-wood residues

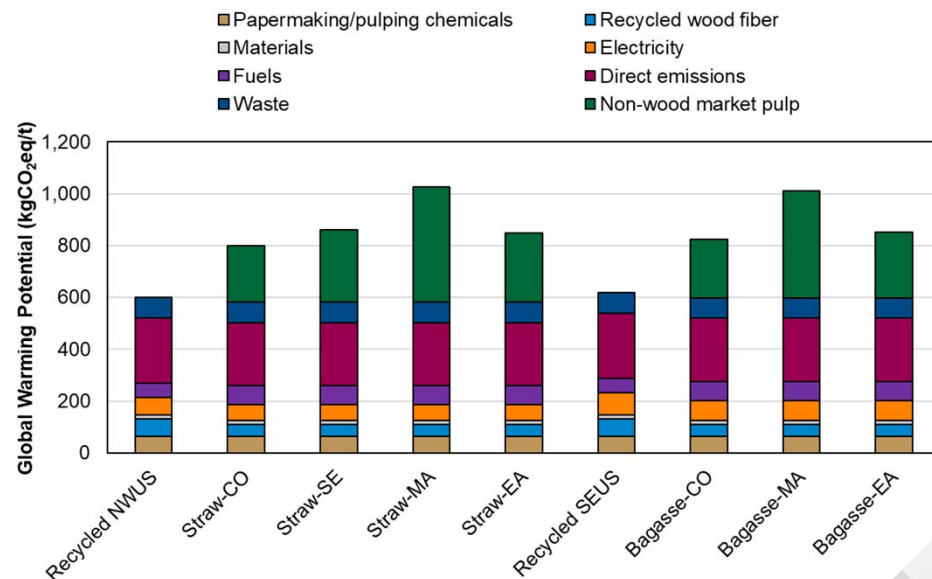


LCCA of linerboard from non-wood residues

- Overall increase in GWP when replacing virgin and recycled fiber with wet-lap non-wood pulp.
- Non-wood pulp is the largest contributor to GWP.



Global warming potential for virgin linerboard containing non-wood residue pulp



Global warming potential for recycled linerboard containing non-wood residue pulp



LCCA of linerboard from non-wood residues

- LCA is dependent on life cycle inventories and assumptions.
- Sensitivity analyses allow to mitigate uncertainty and understand the impact of data variation.

Parameters for sensitivity analysis of non-wood pulp

Variable	Negative variation from the average scenario	Positive variation from the average scenario
Chemical charge	-35% ¹	+35% ¹
Power purchased	-10%	+50% ²
External fuel usage	-20% ²	+20% ²
Yield	-15% ¹	+25% ²
Pulping chemical	Potassium hydroxide ¹ or sodium hydroxide ²	
Transportation*	Bales 5x6 and 4x6 ¹	
Allocation for liquor residue/by-product	Cut-off and mass allocation	

*Only for wheat straw pulp

¹Fisher International, "FisherSolve® Next," Fisher International, Charlotte, NC, United States.; ²Hart, P., TAPPI J. 19(1): 41(2020). <https://doi.org/10.32964/TJ19.1.41>



LCCA of linerboard from non-wood residues

- LCA results highly dependent on life cycle inventory assumptions.
- GWP of non-wood-based packaging between 15-100% higher than benchmarks.
- Besides allocation methods for non-wood residues, the most influent factors are:
 - Allocation methods around by-products of non-wood pulping.
 - Type of pulping chemicals.
 - Chemical charges.



Sensitivity analysis virgin linerboard

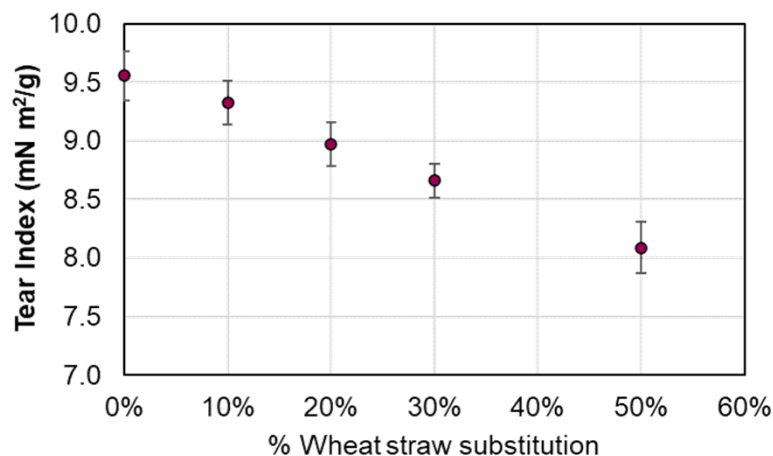


Sensitivity analysis recycled linerboard

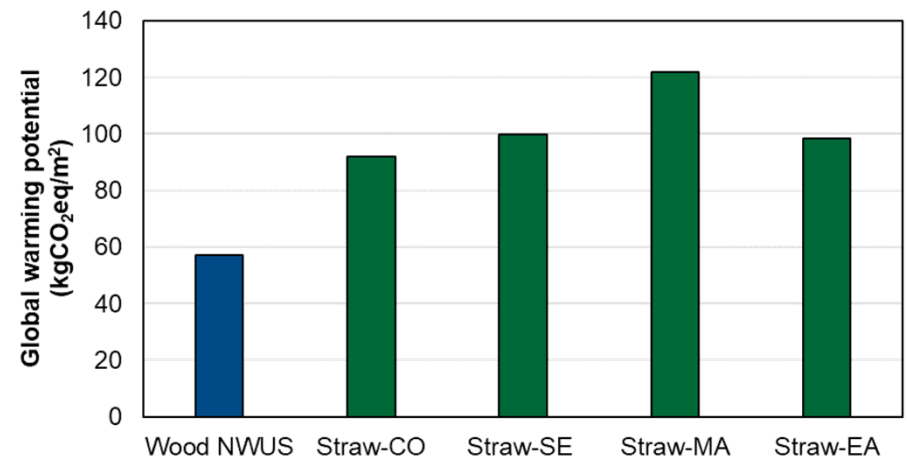


LCCA of linerboard from non-wood residues: Effect of product performance

- Tear and burst indexes decrease as wheat straw substitution increases (STFI and tensile remain similar up to 30% substitution). Tear and burst are selected as examples.
- Decreased properties translate into magnified larger GWPs (ca. 20-30% higher than without considering changes in performance).



Effect of wheat straw substitution on linerboard tear index¹



Effect of changes in tear index on GWP of linerboard containing wheat straw market pulp

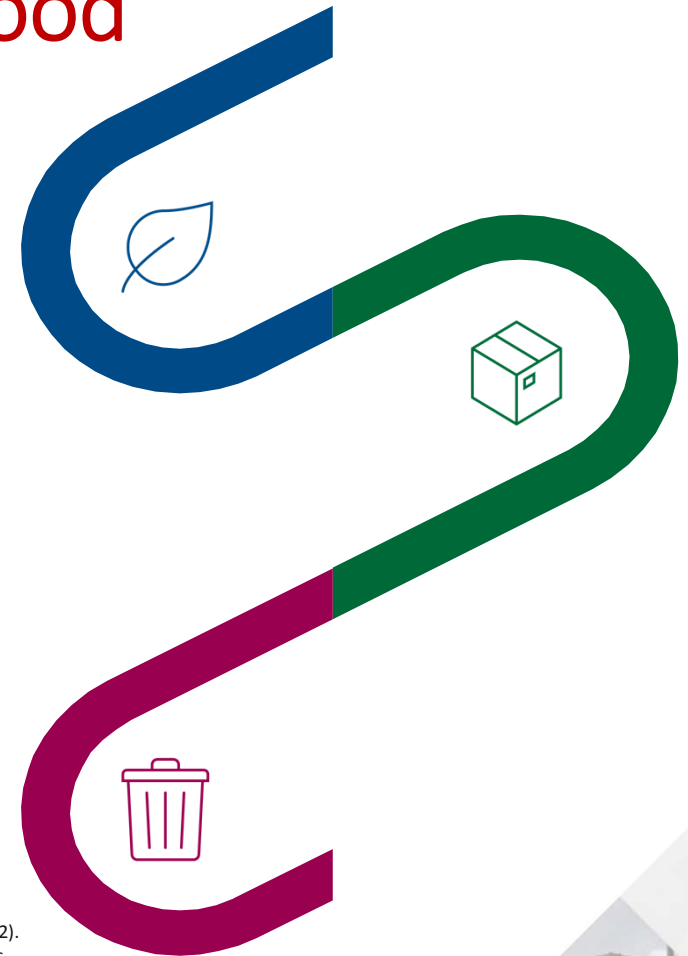
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LCCA of linerboard from non-wood residues: Cradle-to-grave

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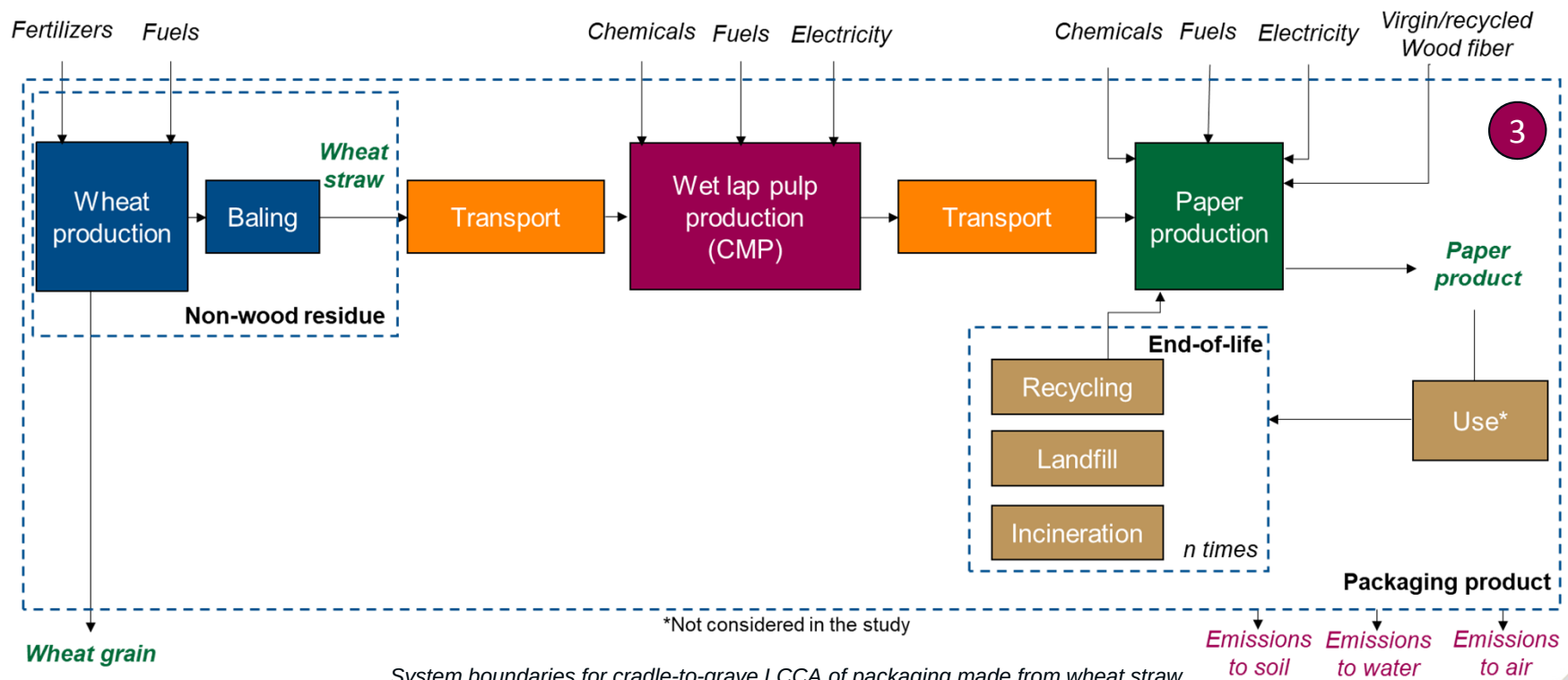
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- **Scope:**
 - **Boundaries:** Cradle-to-grave.
 - **Functional unit:** 1 ton of paper.
 - **Data source:** USLCI, Ecoinvent and FisherSolve Next.
- **Main assumptions:**
 - End-of-life: 82% recycling, 14.5% landfill, and 3.5% incinerated¹.
 - Changes in recycling yield at different cycles was considered².
 - Cascade recycling approach was followed.



¹Anonymous, "Paper and paperboard: Material specific data," United States Environmental Protection Agency, Washington DC, United States. Available [Online] <https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/paper-and-paperboard-material-specific-data> <05May2023>. ²Jirarotepinyo et al. (2022). The Impact of multiple recycle loops on the yield and properties of softwood kraft fibers and of non-wood fibers for packaging TAPPI PEERS Conference Proceedings.



LCCA of linerboard from non-wood residues: Cradle-to-grave



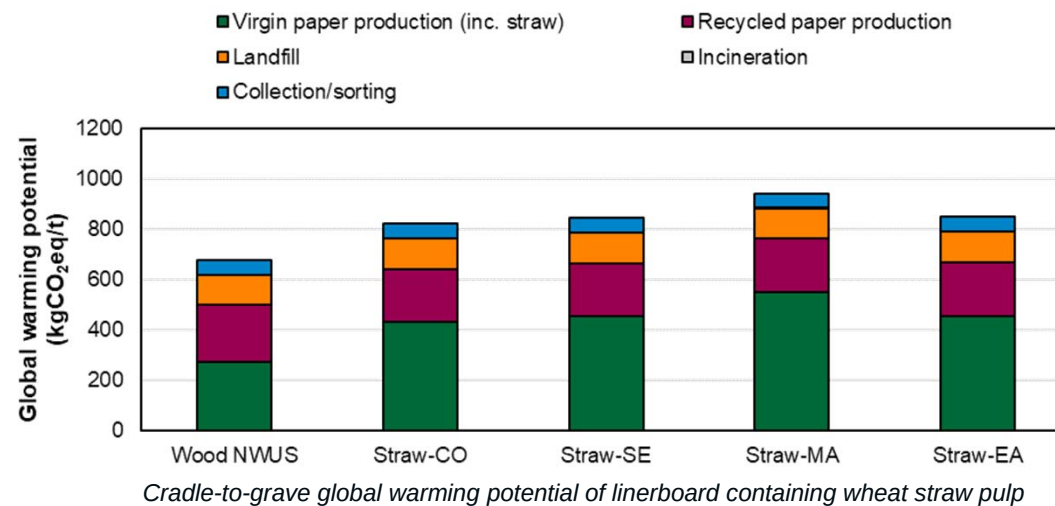
System boundaries for cradle-to-grave LCCA of packaging made from wheat straw

Emissions to soil
Emissions to water
Emissions to air



LCCA of linerboard from non-wood residues: Cradle-to-grave

- GWP of non-wood-based packaging between 21-25% higher than benchmarks.
- Production of virgin paper is the main contributor to the GWP.



Conclusions

- The environmental impact of non-wood residues and derived products highly depends on allocation methods.
- Under the studied conditions, increased GWPs were observed when conventional kraft or recycled fiber was replaced with non-wood wet lap pulp. Intermediate non-wood wet-lap pulp was the driver for this impact (regardless of allocation methods).
- Sensitivity analyses showed that assumptions around the production of pulp greatly influenced results. Thus, the GWPs of packaging products containing residues can be 15%-100% higher than benchmarks under the studied scenarios.
- Including the effect of changes in performance magnified these results for the selected case study (based on tear and burst indexes) based on published data for wheat straw.



Thank you

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