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A Systematic Review of LCA and OpenLCA Applications for Carbon Emission Mapping in Processes

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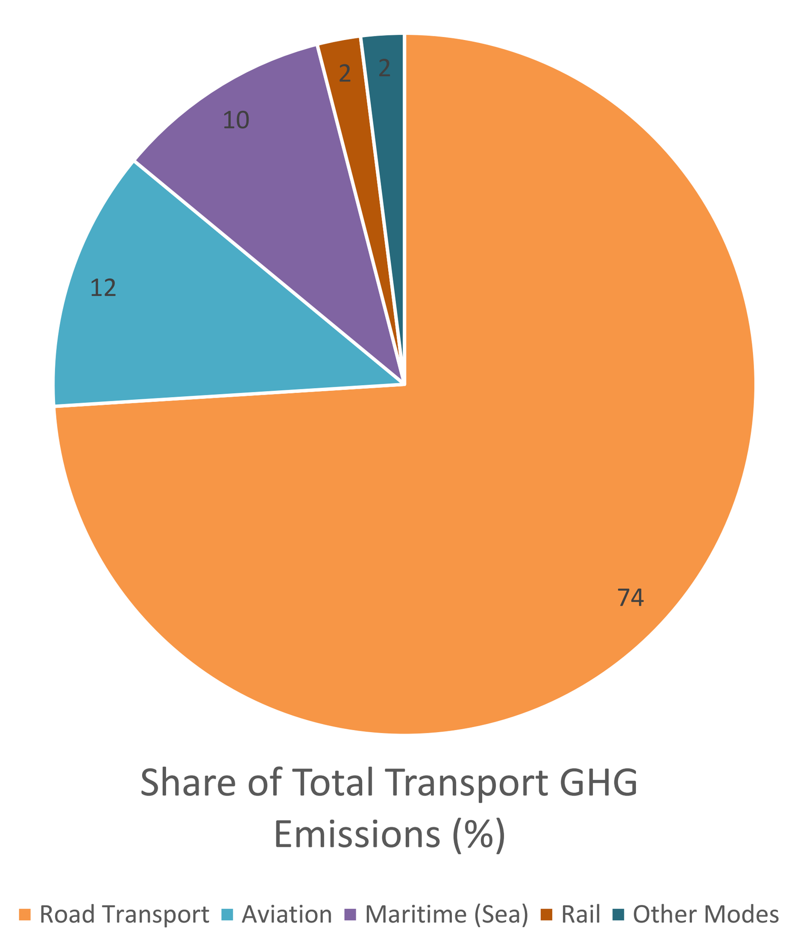
INTRODUCTION & AIM

Introduction

A. Logistics contributes approximately 25% of total GHG emissions (EU data), with last-mile delivery as a major CO_2 source.
B. Last-mile delivery is a key CO_2 & air pollution source.
C. Achieving climate neutrality by 2050 requires identifying emission sources & mitigation paths.
D. Life Cycle Assessment (LCA) evaluates environmental impacts from raw materials to end of life.
E. OpenLCA (open-source, flexible, database-rich) = key platform for process & logistics emission analysis.
F. Despite its wide use, no prior systematic review has focused specifically on the applications of LCA and OpenLCA for emission mapping.



Aim of the Study

1. Conduct a systematic review (2015–2025) of LCA & OpenLCA applications for carbon emission mapping in process sectors.
2. Identify key trends & best practices in emission assessment.
3. Analyze gaps & challenges (data quality, system boundaries, regional contexts).
4. Provide insights for policymakers, researchers, & industries to strengthen sustainable logistics & carbon reduction strategies.
5. This review supports global efforts toward net-zero logistics and SDG 13: Climate Action.

METHOD

Approach

1) Systematic Literature Review (SLR) conducted following PRISMA 2020 guidelines.
2) Focused on applications of LCA & OpenLCA for emission assessment in logistics and process operations.
3) Ensured transparency, repeatability, and consistency in selection.

Search Strategy

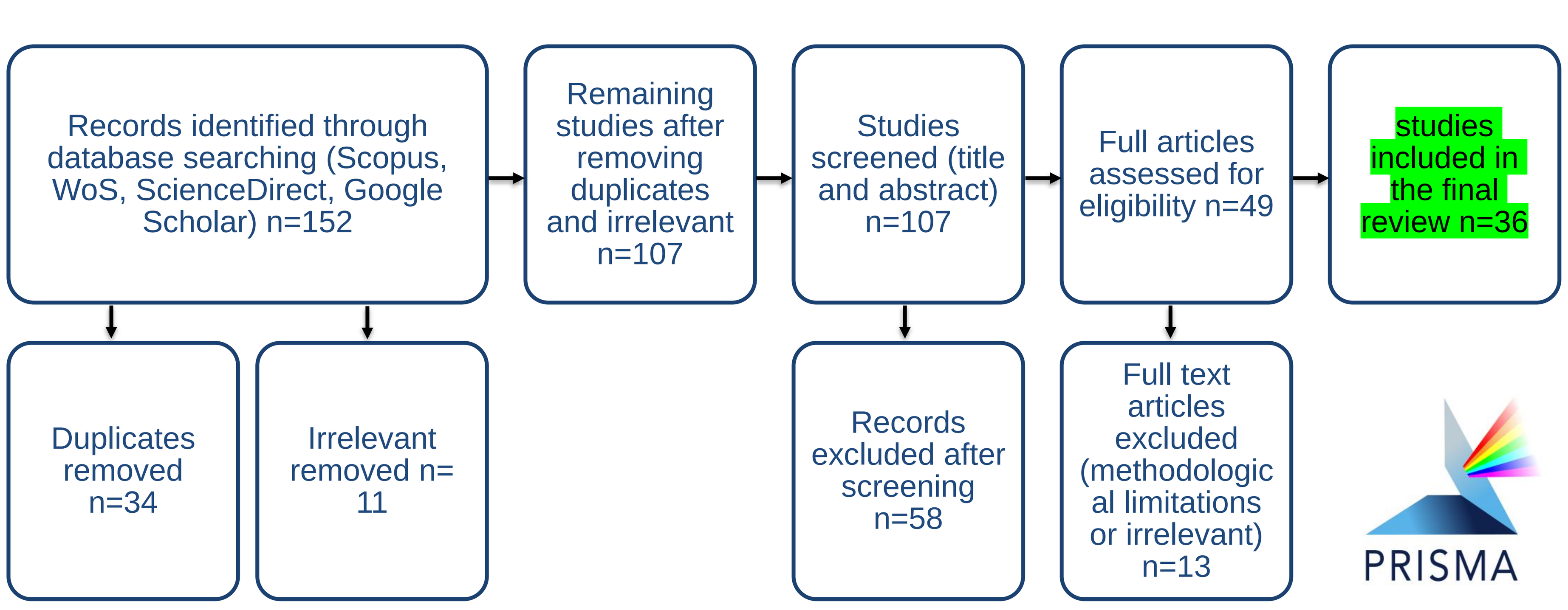
- Databases: Scopus, Web of Science, Google Scholar
- Keywords: Life Cycle Assessment, OpenLCA, logistics, freight, carbon emissions
- Timeframe: 2015 – 2025

Selection Process

- Identification
  - 152 records identified (Scopus, WoS, Google Scholar)
- Screening
  - 95 records after duplicates removed
  - 59 excluded (irrelevant titles/abstracts)
- Eligibility
  - 36 full-text articles assessed
- Included
  - 36 studies included in final synthesis

Analysis

1) Studies grouped by themes (application type, tools, regions).
2) Comparative table created to summarize approaches & findings.
3) Identified trends, limitations, and research gaps in LCA/OpenLCA applications.



RESULTS & DISCUSSION

General Findings

1. LCA is widely applied to logistics systems road, rail, maritime, and urban freight to assess emissions from production to operation.
2. Road transport remains the dominant emitter, as shown in pie chart, while fuel extraction and manufacturing also contribute notably to total impacts.

Role of OpenLCA

1. OpenLCA adopted for analyzing process emissions in Europe & Southeast Asia.
2. Enables transparent, flexible, and low-cost life cycle studies.
3. In Chile, plastic pallets emit more than wooden ones.
4. In Indonesia, transport & logistics identified as top emission sources despite data gaps which Confirms OpenLCA's usefulness in developing regions with limited datasets.

Comparative Insights

1. EVs cut emissions by 50–55% vs diesel vans (Croci et al., 2021).
2. E-cargo bikes further reduce last-mile emissions.
3. Rail/maritime modes outperform road freight in long-distance transport.
4. LCA + Optimization improves cost efficiency and sustainability.
5. These strategies show that combining *technology* (EVs, cargo bikes) with *planning* (modal shift, optimization) yields measurable GHG cuts.

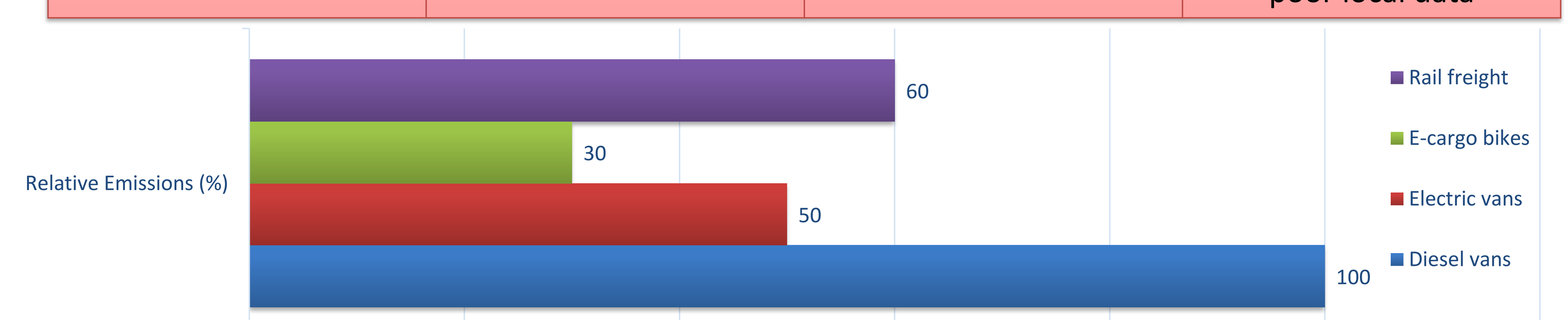
Discussion Highlights

1. Consensus: LCA + OpenLCA = effective tools for greener logistics & emission management.
2. Persistent challenges:
   - Data quality & availability, especially in developing regions.
   - Inconsistent system boundaries & lack of uncertainty analysis.
3. Future research should strengthen local datasets, standardize LCA methodologies, and link LCA with digital twins, drones, and AI-based logistics models.

Key Message

LCA + OpenLCA = transparent, low-cost tools driving emission smart, net-zero logistics.

Study	Tool	Focus Area	Key Finding
Croci et al. (2021)	LCA	Urban last-mile logistics	EVs cut GHG emissions by 50–55%
Vásquez et al. (2022)	OpenLCA	Pallet transport	Plastic pallets emit more than wood
Temporelli et al. (2022)	LCA	City delivery	E-cargo bikes lower emissions vs. vans
Wiloso et al. (2019)	OpenLCA	Logistics (Indonesia)	High emissions due to poor local data



CONCLUSION

- LCA & OpenLCA are powerful tools for assessing and reducing carbon emissions in logistics.
- Integrating LCA with supply-chain optimization improves both cost efficiency and sustainability.
- Key strategies: electric vehicles, modal shifts (rail/sea), and process optimization.
- Main challenges: data gaps, inconsistent system boundaries, and limited uncertainty analysis.
- Future progress requires better local datasets, standardized methods, and broader sustainability scope (environmental, economic, social).
- Collaboration between researchers, industry, and policymakers is vital for achieving low-carbon logistics and net-zero goals.

FUTURE WORK / REFERENCES

1. Develop region-specific emission databases to improve model accuracy.
2. Establish standardized LCA methodologies for consistent global comparisons.
3. Integrate real-time logistics and supply-chain data into OpenLCA models.
4. Expand LCA to include economic and social sustainability indicators.
5. Explore emerging technologies (AI, digital twins, drones, autonomous delivery) for future emission reduction strategies.
6. Strengthen collaboration between academia, industry, and policymakers for data sharing and implementation.